Alternatives Analysis Technical Report
Appendix F: NOISE AND VIBRATION TECHNICAL REPORT

Red Line/Blue Line Connector Project

Boston,
Massachusetts

Massachusetts Department of Transportation
Boston, Massachusetts

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March 2010

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Executive Summary

<u>Background</u>

Potential noise and vibration impact has been assessed for the Red Line / Blue Line Connector Project for transit operations and construction activities based on the methodology defined in the FTA guidance manual "*Transit Noise and Vibration Impact Assessment*" (Report FTA-VA-90-1003-06, May 2006). The Project includes two Build Alternatives 1) eliminating the existing Bowdoin Station and 2) modification of the existing Bowdoin Station. Because these alternatives are very similar, no differences in potential noise or vibration impact and recommended mitigation were found.

Since the proposed Project is to extend the Blue Line in an underground tunnel from Government Center to the Red Line at Charles/MGH Station, airborne noise generated by the trains and underground construction activities will not propagate significantly into the community. Noise from above-ground construction activities has a potential for impacting nearby receptors and has been assessed according to guidelines consistent with the Boston City Noise Ordinance and the Central Artery/Tunnel Noise Specification.

Ground-borne vibration and ground-borne noise, which is produced when ground-borne vibrations propagate into a building and radiate noise from the motion of the room surfaces, have been assessed at sensitive locations along the project. Potential damage to nearby structures, human annoyance at residences and institutional land uses and impact to vibration-sensitive equipment have been assessed for ground-borne vibrations generated by transit operations and construction activities. Ground-borne noise has been assessed at residences and institutional land uses for transit operations and underground construction using a tunnel boring machine and muck trains to move excavate inside the tunnels.

Above-ground construction methods assessed for potential noise and vibration impact include pier reconstruction and ventilation shaft drilling, jet grouting, utility relocation, cut and cover excavation, and ventilation structure / building construction. The primary construction equipment generating airborne noise and ground-borne vibration include the jackhammer, dump truck, drilling rig, jet grouting, clam shovel, hoe ram and concrete trucks. For assessing construction noise impact, a "worst case" noise condition is assumed where many of the significant construction noise sources are present at the same time.

Noise and vibration-sensitive locations in the study area include multi-family residential buildings, hotels, hospitals, schools, parks, a television studio, a library, a

church, a museum and a fire department with housing. During daytime construction activities, the aforementioned land uses as well as commercial and industrial areas are considered sensitive to noise. Vibration-sensitive locations also include hospital beds, operating rooms and equipment within the Massachusetts General Hospital (MGH) and Massachusetts Eye and Ear Infirmary (MEEI). Examples of vibration-sensitive equipment at these research facilities include imaging scanners such as MRI's and CT scanners, microscopes and laser-based equipment.

Existing Conditions

The noise criteria applicable for potential impact from transit operations depend on existing Ldn noise levels at residences, hotels and hospital beds and existing peak transit-hour Leq noise levels at institutional land uses. Construction noise criteria depend on existing L10 noise levels during the daytime (7:00 AM to 6:00 PM), evening (6:00 PM to 10:00 PM) and nighttime (10:00 PM to 7:00 AM) at all sensitive locations (including commercial and industrial land uses). Existing noise measurements were conducted at six locations throughout the StudyArea to characterize these existing conditions. At the closest receptors, existing Ldn noise conditions range from 67 to 76 dBA, peak-transit hour Leq values range from 65 to 74 dBA and L10 values range from 63 to 71 dBA during the daytime, 65 to 73 dBA during the evening and 58 to 70 dBA during the nighttime.

Vibration criteria for potential damage to structures and potential annoyance to humans do not depend on existing vibration levels; however, the existing vibration conditions are useful for conducting an investigation into the potential affect of the Project on vibration-sensitive equipment. Existing vibration conditions at MGH and MEEI near sensitive equipment which are closest to the proposed project are generally within the VC-C to VC-D detailed vibration criteria (on the building floors, not including any potential vibration isolation of the equipment mounting). VC-D is suitable in most instances for the most demanding equipment including electron scanning microscopes operating to the limits of their capability (see Section 1.3.3 for more detail).

Impact Assessment

For long-term train operations, no airborne noise impact is expected at any of the sensitive locations. For short-term construction activities, a "worst case" scenario of potential noise impact without mitigation indicates that 26 residential properties and 26 institutional and commercial properties may be exposed to construction noise impact. L10 construction noise levels are generally 80 to 90 dBA at the closest receptors (typical daytime criterion is 75 dBA for residences and 80 dBA for commercial land uses, typical evening criterion is 65 to 78 dBA at residences and typical nighttime criterion is 65 to 70 dBA at residences).

Potential ground-borne noise impact from transit operations is projected at four multi-family residences between station numbers 4+00 and 8+00 due primarily to their proximity to the double crossover which increases ground-borne noise and vibration levels due to the gaps in the rail running surface. Ground-borne noise is projected to be between 35 and 41 dBA at these locations (residential criterion is 35 dBA). No ground-borne noise impact is projected from either the tunnel boring machine or muck trains.

Potential damage to nearby structures from construction activities is projected at a multi-family residential building at 315 Cambridge Street and a MEEI building at 325 Cambridge Street without mitigation. These buildings are expected to be approximately 10 feet away from the construction “starter hole” where a clam shovel may be used for cut and cover excavation and drilling for jet grouting the adjacent soil. The vibration level at the ground level of these buildings is projected to be 106 VdB from a clam shovel dropping at 10 feet and 99VdB and from drilling (damage criterion for these engineered concrete and masonry buildings is 98 VdB). This assessment does not include any potential damage to structures due to soil settlement or displacement caused by construction activities.

There is no projected ground-borne vibration impact from transit operations to residences, hotels, hospital beds or institutional land uses. Ground-borne vibration from transit operations at vibration-sensitive equipment at MGH and MEEI is projected to be below the VC-E criterion at all locations except for the MEEI Angiogenesis Lab at 325 Cambridge Street where vibrations from transit operations are projected to be below the VC-C criterion. Since existing vibration levels at sensitive equipment is typically at VC-B or VC-C levels, transit operations are not expected to cause any adverse effect. The sensitive equipment at the Angiogenesis Lab is a 100x magnification microscope which typically will only require vibration levels to be below the residential nighttime/operating room criterion (72 VdB) to avoid impact. Interior vibration levels at the 3rd floor of this building are projected to be 54 VdB and well below the impact criterion.

Potential human annoyance from short-term construction vibration activities is projected at five sensitive receptors including the Angiogenesis Lab at 325 Cambridge Street and multi-family residences at 315 Cambridge Street. The primary construction equipment of concern at these locations is the clam shovel used during cut and cover excavation and drilling for jet grouting the adjacent soil. Interior vibration levels are projected to be 73 to 100 VdB at these locations (residential criterion is 72 VdB and institutional criterion is 75 VdB).

The potential for short-term construction vibration impact on vibration-sensitive equipment at MGH and MEEI has also been assessed for the clam shovel and drilling for jet grouting. For most sensitive equipment at MGH and MEEI, vibration levels from construction activities are projected to be below existing levels. At three locations, vibrations from construction activities may temporarily increase levels. At

the main MEEI building at 243 Charles Street, projected construction vibration levels (47 VdB) are expected to be below the VC-D criterion while existing vibration levels meet the VC-E criterion (42 VdB). At the MGH Yawkey building 6th floor MRI, projected construction vibration levels (58 VdB) are expected to be below the VC-B criterion while existing vibration levels meet VC-C criterion (54 VdB). Although vibration levels may increase slightly at these two locations during construction, they are still relatively low and are not expected to cause any adverse effect to the MRI's at these locations. At the MEEI Angiogenesis Lab at 325 Cambridge Street, construction vibration levels (98 VdB) are projected to exceed the operating room general criterion (72 VdB).

Mitigation

Construction noise is dependent on the specific equipment used, the location of equipment and the duration of use. These details ultimately depend on the contractor's methods of construction. Therefore, assessing and mitigating potential construction noise impact is a process that occurs immediately prior to and during construction. Construction noise mitigation includes the preparation of a Noise Control Plan in conjunction with the contractor's specific equipment, schedule and methods of construction; maximum noise limits for each piece of equipment; prohibitions on certain types of equipment during the nighttime hours and engineering noise control measures. Noise control measures include shields, shrouds or intake and exhaust mufflers, noise deadening materials adhered to chutes or storage bins, temporary noise barriers, acoustic enclosures, specialized back-up alarms, limiting the size of generators and the duration of their use and using truck routes that minimize exposure to sensitive receptors.

To mitigate potential ground-borne noise impact from transit operations at residences in close proximity to the double crossover, the use of spring-rail frogs, moveable-point frogs or flange-bearing frogs will eliminate the impact at this location.

The MEEI building at 325 Cambridge Street and the multi-family residential building at 315 Cambridge Street may potentially be exposed to vibrations from construction activities which could cause damage, annoy humans within the buildings and affect vibration-sensitive equipment in the Angiogenesis Lab without mitigation. To mitigate these potential impacts, the contractor will need to use specific construction methods and equipment to minimize the potential for damage, annoyance and affects on special equipment. Such methods may involve not using a clam shovel for excavation, not using a typical drill rig prior to jet grouting or using a particular drill rig which generates lower vibrations. Given the close proximity of the construction activities to the building, other mitigation measures such as trenches or wave barriers are likely infeasible.

Noise

The Secretary's Certificate on the EENF requires that the DEIR analyze noise for existing and proposed conditions consistent with FTA guidelines. The Certificate requires that this analysis identify the location of noise-sensitive receptors, assess the potential for noise impact from both transit operations and construction, and specify both where mitigation is required and what mitigation measures will be used.

The noise impact analysis for the Red Line Blue Line Connector Project is based on the methodology defined in the FTA guidance manual "*Transit Noise and Vibration Impact Assessment*" (Report FTA-VA-90-1003-06, May 2006). The analysis includes background on the noise impact assessment methodology, environmental consequences of the project including noise impact results for two proposed Build Alternatives, the type and location of specific measures required to mitigate potential significant noise impacts, and a summary of results.

This section describes the existing noise conditions and environmental consequences along the proposed Red Line/Blue Line Connector Project including:

- Background information on airborne noise
- Description of noise-sensitive land use categories
- Identification of noise-sensitive locations along the corridor
- Noise impact criteria for transit operations and construction activities
- Measurement results of existing noise conditions
- Noise projection methodology
- Impact assessment from transit operations and construction activities
- Recommended noise mitigation
- Summary of findings

1.1 Affected Environment

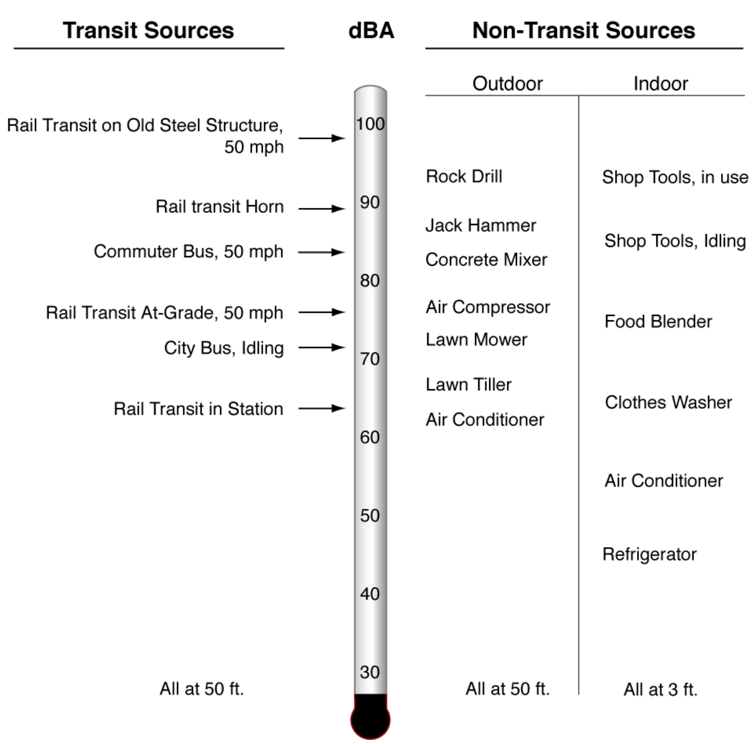
1.1.1 Introduction

Noise is typically defined as unwanted or undesirable sound, where sound is characterized by small air pressure fluctuations above and below the atmospheric pressure. The basic parameters of environmental noise that affect human subjective response are (1) intensity or level, (2) frequency content and (3) variation with time. The first parameter is determined by how greatly the sound pressure fluctuates above and below the atmospheric pressure, and is expressed on a compressed scale

in units of decibels. By using this scale, the range of normally encountered sound can be expressed by values between zero and 120 decibels. On a relative basis, a three-decibel change in sound level generally represents a barely-noticeable change outside the laboratory, whereas a 10-decibel change in sound level would typically be perceived as a doubling (or halving) in the loudness of a sound.

The frequency content of noise is related to the tone or pitch of the sound, and is expressed based on the rate of the air pressure fluctuation in terms of cycles per second (called Hertz and abbreviated as Hz). The human ear can detect a wide range of frequencies from about 20 Hz to 17,000 Hz. However, because the sensitivity of human hearing varies with frequency, the A-weighting system is commonly used when measuring environmental noise to provide a single number descriptor that correlates with human subjective response. Sound levels measured using this weighting system are called "A-weighted" sound levels, and are expressed in decibel notation as "dBA." The A-weighted sound level is widely accepted by acousticians as a proper unit for describing environmental noise. To indicate what various noise levels represent, Figure 1.1-1 shows some typical A-weighted sound levels for both transit and non-transit sources. As indicated in this figure, most commonly encountered outdoor noise sources generate sound levels within the range of 60 dBA to 90 dBA at a distance of 50 feet.

Figure 1.1-1 Typical A-Weighted Sound Levels



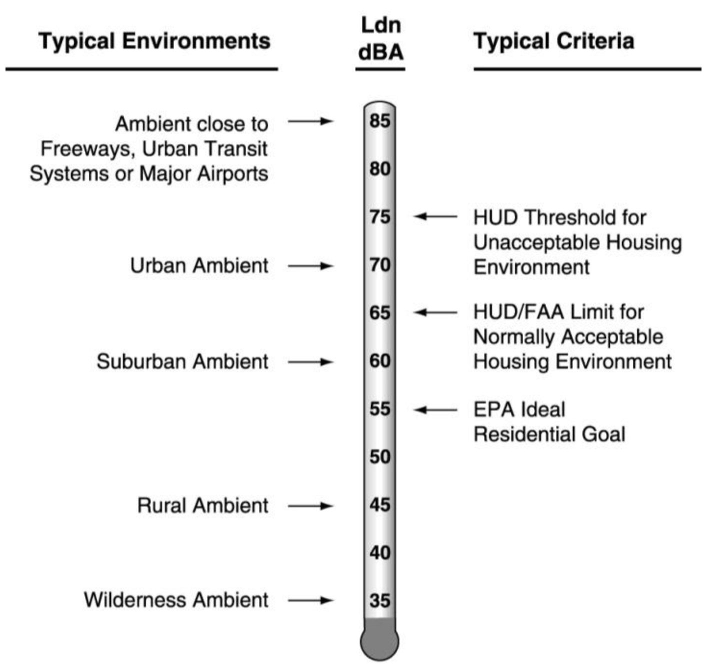
Source: FTA, 2006.

Because environmental noise fluctuates from moment to moment, it is common practice to condense all of this information into a single number, called the "equivalent" sound level (Leq). Leq can be thought of as the steady sound level that represents the same sound energy as the varying sound levels over a specified time period (typically one hour or 24 hours). Often the Leq values over a 24-hour period are used to calculate cumulative noise exposure in terms of the Day-Night Sound Level (Ldn). Ldn is the A-weighed Leq for a 24-hour period with an added 10-decibel penalty imposed on noise that occurs during the nighttime hours (between 10 PM and 7 AM).

Other metrics to describe noise include statistical percentiles such as L10, which is defined as the noise level which is exceeded 10 percent of the time over a specified measuring period. While the L10 is not the maximum noise level, it describes the higher noise levels that are present in the community.

Many surveys have shown that Ldn and Leq are well correlated with human annoyance, and therefore these descriptors are widely used for environmental noise impact assessment from permanent noise sources such as transit operations. As described in further detail in the following section, Ldn is used to assess potential impact from transit operations at residential land uses and peak-transit hour Leq (6:30 AM to 9:30 AM and 3:30 PM to 6:30 PM) is used to assess potential impact at institutional land uses from transit operations. For construction noise sources the L10 metric is used to assess potential impact.

Figure 1.1-2 Examples of Typical Outdoor Noise Exposure



Source: Harris Miller Miller & Hanson, 2009

Figure 1.1-2 provides examples of typical noise environments and criteria in terms of Ldn. While the extremes of Ldn are shown to range from 35 dBA in a wilderness environment to 85 dBA in noisy urban environments, Ldn is generally found to range between 55 dBA and 75 dBA in most communities. As shown in Figure 1.1-2, this spans the range between an ideal residential environment and the threshold for an unacceptable residential environment according to U.S. Federal agencies such as the U.S. Department of Housing and Urban Development and the U.S. Environmental Protection Agency.

1.1.2 Noise-Sensitive Land Use Categories

The FTA classifies land uses sensitive to noise from transit operations into the following three categories.

- Category 1: Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
- Category 2: Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity is assumed to be of utmost importance.
- Category 3: Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

There are some buildings, such as television studios, concert halls, recording studios and theaters that can be very sensitive to noise and/or vibration but do not fit into any of the three categories. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project.

In addition to the land use categories defined by FTA, the applicable construction noise criteria includes commercial and industrial land uses as noise-sensitive locations for daytime construction activities (7:00 AM to 6:00 PM). Institutional and commercial properties are not sensitive to noise during evening (6:00 PM to 10:00 PM) or nighttime (10:00 PM to 7:00 AM) construction activities.

1.1.2.1 Noise-Sensitive Land Use

Noise-sensitive land use in the Red Line/Blue Line Connector Project Study Area was identified primarily during field visits with supplemental information provided by personnel at MGH and MEEI hospitals.

Land use in the Study Area which is sensitive to noise from transit operations and construction activities includes multi-family residential properties, hotels, hospitals, schools, parks, a television studio, a library, a church, a museum and a fire department with housing. In addition, there are commercial areas (businesses, offices, stores) which are sensitive to daytime construction noise. Many of the closest residential buildings along the study area are four or six stories tall with commercial land use on the first floor.

<u>From Western Terminus to Blossom Street</u>

Residential properties in this section of the alignment include multi-family buildings on Cambridge Street and buildings on Cedar Street, Lindall Place, Grove Street, Strong Place, Anderson Street and Garden Street which are generally set back further from Cambridge Street.

The MGH campus and MEEI are in this section of the alignment. Some of the MGH buildings which are sensitive to noise in this section include the Yawkey building, which is approximately 100 feet from the proposed alignment, the Northeast Proton Therapy Center, which is approximately 300 feet from the proposed alignment and other buildings such as Wang, Barlett, Barlett Extension, Ellison, White and Founders, which are generally 400 to 700 feet from the proposed alignment. MEEI is located at the corner of Charles Street and Fruit Street which is approximately 450 feet from the proposed alignment. These hospital buildings have other intervening buildings providing acoustical shielding between them and the alignment

<u>Blossom Street to New Chardon Street</u>

This section of the alignment includes multi-family residential buildings on the south side of Cambridge Street and buildings on Irving Street, Russell Street, Joy Street, Hancock Street, Ridgeway Lane and Temple Street which are set back further from Cambridge Street. The Boston Fire Department District 3 Ladder 24, which includes housing for the firefighters, is located in this area. Other sensitive locations include the Holiday Inn, the Simches building and North Anderson Street Park on the MGH campus, the Boston Public Library West End Branch, a nursery school and park on Joy Street, the Otis House Museum and the Old West Church. There are commercial spaces on the first floor of most of the buildings on the south side of Cambridge Street as well as the Charles River Plaza and the Massachusetts Health, Welfare and Education building at 115 Cambridge Street on the north side of Cambridge Street.

New Chardon Street to Eastern Terminus

In this section of the alignment there are several multi-family residential buildings on Cambridge Street between Temple Street and Bowdoin Street including residential properties at 100 Cambridge Street. Other sensitive land use in this section includes the Cardinal Cushing Memorial Park and the WHDH/WLVI Television Studio at 7 Bulfinch Place. Commercial spaces which are sensitive to daytime construction noise include a 22-story state agency building at 100 Cambridge Street, offices at One Bowdoin Square, offices at the New England Telegraph and Telephone Company building at 65 Cambridge Street, the John F. Kennedy Federal Building at 15 New Sudbury Street, Center Plaza and Boston City Hall Plaza.

1.1.3 Noise Impact Criteria

1.1.3.1 Transit Operations

The FTA noise impact criteria are founded on well-documented research on community reaction to noise and are based on change in noise exposure using a sliding scale. Lower levels of transit noise are allowed in areas where existing noise levels are relatively low since the introduction of a new noise source can be more perceptible under these conditions. In neighborhoods where existing noise levels are higher, higher levels of transit noise are allowed since the existing noise will tend to mask the new source. With this sliding scale, however, the allowable increase in total future noise exposure (existing plus project noise) decreases as existing noise levels increase so that environments with higher noise levels are not allowed to increase substantially.

The Day-Night Sound Level (Ldn) is used to characterize noise exposure for residential areas (Category 2). For other noise sensitive land uses, such as parks, libraries, schools and museums (Categories 1 and 3), the peak-transit hour Leq (during morning and afternoon peak) is used. Ldn and Leq are explained in Section 1.1.1.

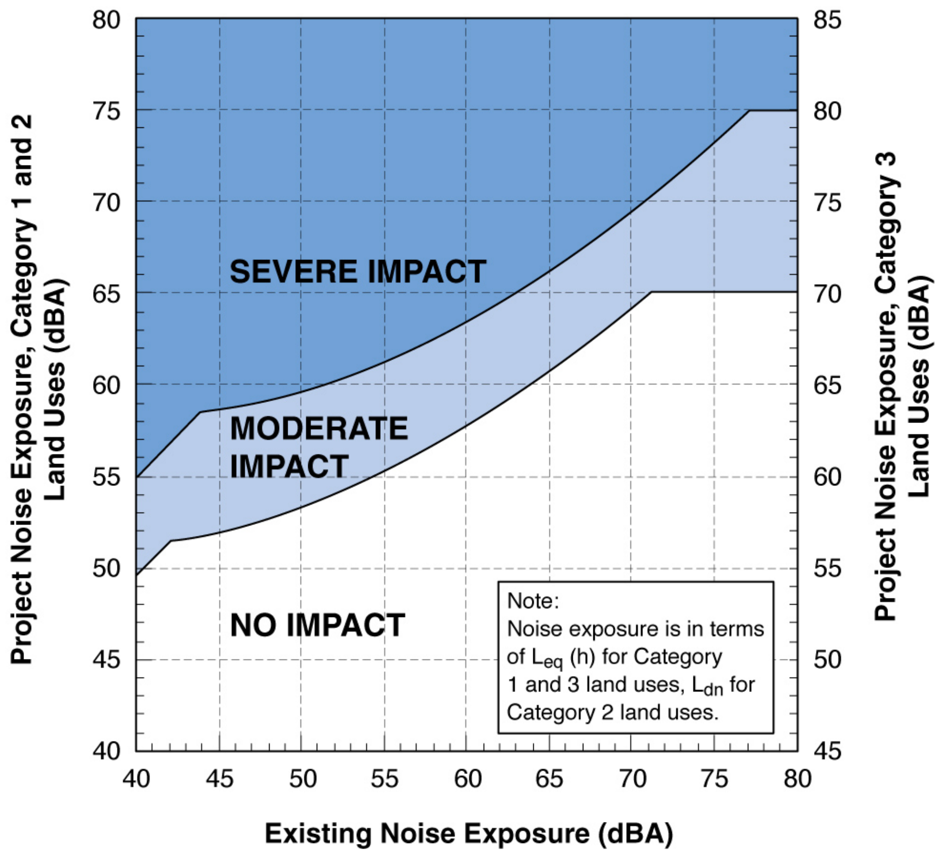
There are two levels of airborne noise impact included in the FTA criteria, as summarized below.

- Severe Impact: Project-generated noise in the severe impact range can be expected to cause a significant percentage of people to be highly annoyed by the new noise and represents the most compelling need for mitigation. Noise mitigation will normally be specified for severe impact areas unless there are truly extenuating circumstances that prevent it.
- Moderate Impact: In this range of noise impact, the change in the cumulative noise level is noticeable to most people but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other

project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These factors include the existing noise level, the predicted level of increase over existing noise levels, the types and numbers of noise-sensitive land uses affected, the noise sensitivity of the properties, the effectiveness of the mitigation measures, community views and the cost of mitigating noise to more acceptable levels.

The FTA noise impact criteria are shown in graphical form in Figure 1.1-3. Along the horizontal axis of the graph is the existing noise exposure and the vertical axis shows the additional noise exposure from the transit project that would cause either moderate or severe impact.

Figure 1.1-3 FTA Noise Impact Criteria



Source: FTA, 2006.

1.1.3.2 Construction Activities

Noise impact for temporary construction activities is treated differently than the permanent noise exposure of transit operations. The construction noise criteria applicable to this project are based on the Central Artery/Tunnel (CA/T) Noise

Control Specification 721.560. This specification is consistent with the City of Boston Noise Ordinance and provides further detail on establishing noise criteria limits according to time of day and type of sensitive land use, defining allowable limits for the maximum noise emissions of specific equipment, requirements for a noise monitoring plan to be prepared prior to construction, noise monitoring equipment, noise reduction measures and reporting requirements.

Construction lot-line noise limits depend on the time of day (daytime, evening or nighttime) and the type of sensitive land use (FTA-defined sensitive land use, commercial areas and industrial areas). These criteria are based on the L10 noise descriptor. For daytime construction (7:00 AM to 6:00 PM), the limits are defined as the greater of 75 dBA or the background or ambient level plus 5 dBA for FTA-defined noise sensitive sites, 80 dBA or the background plus 5 dBA for commercial areas and 85 dBA or the background plus 5 dBA for industrial areas. For evening construction (6:00 PM to 10:00 PM), the L10 limit for FTA-defined noise sensitive sites is the background plus 5 dBA. For nighttime construction (10:00 PM to 7:00 AM), the L10 limit for FTA-defined noise sensitive sites is the background plus 5 dBA (if background is less than 70 dBA) and plus 3 dBA (if the background is greater than 70 dBA). Commercial and industrial areas are not considered to be sensitive to construction noise during the evening or nighttime since they are generally closed during these periods.

Table 1.1-1 Construction Lot-Line Noise Limits

Land Use (c)	Time of Day	L10 Level (dBA)	Lmax Level (dBA)
FTA Land Use Categories (1,2,3)	Daytime	75 or Background + 5 (a)	85 (b) / 90 (impact equip.)
Commercial	Daytime	80 or Background + 5 (a)	None
Industrial	Daytime	85 or Background + 5 (a)	None
FTA Land Use Categories (1,2,3)	Evening	Background + 5	85
Commercial	Evening	None	None
Industrial	Evening	None	None
FTA Land Use Categories (1,2,3)	Nighttime	Background + 5 (existing < 70)	80
FTA Land Use Categories (1,2,3)	Nighttime	Background + 3 (existing > 70)	80
Commercial	Nighttime	None	None
Industrial	Nighttime	None	None

Source: CA/T Noise Specification 721.560

a Noise from impact equipment is exempt from this requirement.

b All measurements shall be taken at the affected lot-line. In situations where the work site is within 50 feet of a lot-line, the measurement shall be taken from a point along the lot-line such that a 50 foot distance is maintained between the sound level meter and the construction activity being monitored.

c Lot-line noise limits shall apply to all points along the receptor's lot-line.

The construction noise limits used in this analysis are approximate because the Noise Control Specification requires that site-specific background L10 measurements be conducted more immediately prior to construction in order to define the allowable limits.

In addition to construction lot-line noise limits, noise limits at 50 feet for specific equipment have been identified. A list of these construction noise limits is provided in the Appendices.

1.1.4 Existing Noise Conditions

This section discusses the existing noise environment in the Study Area including measurement methodology and noise measurement results.

1.1.4.1 Noise Measurement Methodology

Existing noise measurements were conducted at locations representative of noise-sensitive receptors. All noise measurement equipment is calibrated in the field and to a laboratory traceable to the National Institute of Standards and Technology.

Both long-term (24-hours or longer) and short-term (1-hour) noise measurements have been conducted. Long-term measurements provide a direct measurement of both Ldn and peak transit-hour Leq. Short-term measurements provide a direct measurement of peak transit-hour Leq and Ldn levels can be estimated based on methods described in the FTA guidance manual. In addition to Ldn and peak-transit hour Leq, the L10 statistical percentiles have been measured at both long-term and short-term sites.

Existing noise measurement sites were selected based on their proximity to the proposed alignment and how well they represent typical noise-sensitive land use in the area.

1.1.4.2 Existing Noise Measurement Results

To characterize the existing noise conditions in the Study Area, two long-term (48-hour) and four short-term (1-hour) measurements were conducted. These measurement locations are shown in Figure 1.1-4. Long-term measurements were conducted on an elevated balcony area at the Otis House Museum (N-2) and on a second-story roof on top of 316 Cambridge Street (N-5). The average 24-hour Ldn over both days were calculated from these 48-hour measurements as well as peak-transit hour Leq and hourly L10 values. These measurement sites accurately represent the location of most first-row noise-sensitive receptors in the Study Area. The measurement location at 316 Cambridge Street is similar to many of the noise-

sensitive receptors on the alignment which include residences on the second floor or higher on Cambridge Street. The microphone was placed on the façade of the building, so a three decibel correction was made to the noise results to account for reflections from the building.

Short-term measurements were conducted at the Cardinal Cushing Memorial Park (northeast corner of Cambridge Street and new Chardon Street), Boston Fire Department District 3 Ladder 24 (southeast corner of Cambridge Street and South Russell Street), North Anderson Street Park at Massachusetts General Hospital (MGH) (northeast corner of Cambridge Street and North Anderson Street) and the Liberty Hotel (facing Charles Street). Noise and vibration measurement locations are shown in Figure 1.1-4.

Table 1.1-2 presents the noise measurements results. The dominant noise source is vehicular traffic on Cambridge Street including a relatively high level of horn use and emergency sirens from ambulances accessing MGH and MEEI and fire engines. Ldn values in the Study Area range from 67 to 76 dBA. Peak-transit hour Leq values in the Study Area range from 65 to 74 dBA. L10 values in the Study Area range from 63 to 71 dBA during the daytime, 65 to 73 dBA during the evening and 58 to 70 dBA during the nighttime.

Table 1.1-2 Existing Noise Measurement Results

Measurement Site	Location	Distance to Cambridge St. Center Lane of Travel (feet)	Existing Day-Night Level (Ldn)	Existing Peak-Transit Hour Level (Leq)	Existing Daytime 7AM - 6PM (L10)	Existing Evening 6PM - 10PM (L10)	Existing Nighttime 10PM - 7AM (L10)	Duration (hours)
N-1	Cardinal Cushing Park	50	71	66	67 b	65 b	64 b	1
N-2	Otis House Museum	30	75 a	70	70	69	67	48
N-3	Boston Fire Department	40	77	72	73 b	71 b	70 b	1
N-4	North Anderson Street Park	60	68	66	64c	65 c	58 c	1
N-5	316 Cambridge Street	30	76 a	74	72	73	67	48
N-6	Liberty Hotel	40	67	65	63 c	65 c	58 c	1

Source: HMMH, 2009.
a Ldn is average of two 24-hour measurements.
b Ldn and L10 estimated based on same hourly measurement at long-term site N-2.
c Ldn and L10 estimated based on same hourly measurement at long-term site N-5.

1.2 Environmental Consequences

The environmental consequences of the proposed Project are presented in this section including noise projection methodology for transit operation and construction activities, an assessment of potential noise impact and recommended mitigation.

1.2.1 Noise Projections

Noise projections have been made at sensitive receptors to assess potential airborne impact from transit operations and construction activities. Existing noise conditions have been estimated at all sensitive receptors since the impact criteria depend on existing or background noise levels. Airborne noise projections are primarily focused on construction activities since the only above-ground noise sources include ventilation shafts and a traction power substation (TPSS).

1.2.1.1 Background Noise

Existing noise conditions were measured at six locations throughout the Study Area. To characterize existing Ldn, Leq and L10 noise conditions at all sensitive receptors, estimations of existing noise have been made based on these measurements. Since the dominant noise source in the Study Area is vehicular traffic on Cambridge Street, existing noise levels are primarily a function of the distance from Cambridge Street and the presence of any acoustical shielding, such as intervening buildings. Existing noise levels have been estimated based on the nearest long-term or short-term noise measurement location, the relative distances to Cambridge Street and the number of intervening building rows as follows:

L (projected location) = L (measurement location) + 25* Log (D (projected location)/ D (measurement location)) – S

where;

L = Ldn, Leq or L10 noise level

D = Distance to center of near lanes of travel on Cambridge Street

S = Acoustic shielding from intervening buildings.

1.2.1.2 Transit Operations

Airborne noise sources considered for this underground tunnel alignment include a TPSS and ventilation fans. Noise sources within a TPSS include electrical noise from

transformers and heating, ventilation and air-conditioning (HVAC) sources required to maintain a suitable environment for the transformers.

The American Public Transportation Association (APTA) has guidelines for noise from ancillary facilities such as a TPSS. According to these guidelines, the TPSS should be designed to generate a maximum noise level of 45 dBA at 50 feet for high-density residential areas (50 dBA at 50 feet for commercial areas).

Airborne noise from ventilation shafts is projected based on measurements of ventilation shaft fan noise on other existing transit systems. Projections of Leq, Ldn and L10 noise levels from TPSS and ventilation shafts are made according to the following equations. Since these noise sources are constant, the Leq also represents the maximum noise level.

Lmax = 50 dBA at 50 feet (TPSS) or 41 dBA at 50 feet (Ventilation Fans)

Leq (receptor location) = Lmax - 20 * Log(receptor distance/50)

Ldn (receptor location) = 10* Log(15 * 10^(Leq/10) + 9 * 10^(Leq+10 dBA/10)) – 13.8

L10 (receptor location) = Leq + 3 dBA

1.2.1.3 Construction Activities

Above-ground construction methods assessed for potential noise impact include pier reconstruction and ventilation shaft drilling, jet grouting, utility relocation, cut and cover excavation, and ventilation structure / building construction. Construction noise is dependent on the specific equipment used, the location of equipment and the duration of use. These details ultimately depend on the contractor’s methods of construction. Therefore, assessing and mitigating potential construction noise impact is a process that occurs immediately prior to and during construction. Background noise measurements are conducted at specific locations, a construction noise control plan is prepared projecting construction noise levels based on the contractor’s intended activities and necessary mitigation is implemented during construction.

To assess potential impact, the following construction noise projections represent a “worst case” noise condition assuming that many of the significant construction noise sources are present at the same time. Construction noise is projected based on the maximum noise level of each piece of equipment and the “usage factor” which adjusts the maximum noise levels for the typical duty cycle the equipment is in use. L10 construction noise levels at sensitive receptors are projected using the following equations:

Leq at 50 ft (individual equipment) = Lmax + 10*Log(Usage Factor %)

Leq at 50 ft (cumulative) = Sum of all individual equipment

L10 at 50 ft = Leq + 3 dBA

L10 at receptor = L10 at 50 ft – 20*Log(distance to receptor/50) – S

where;

S = Acoustic shielding from intervening buildings.

Construction activities for Alternatives 1 and 2 are relatively similar in regard to potential noise impact. Table 1.2-1 shows the reference L10 construction noise levels for each method. Often the most significant noise source for construction equipment is the diesel engine. This table shows that at 50 feet, "worst case" L10 construction noise levels range from 83 to 92 dBA. The distances to potential construction noise impact without mitigation for a typical residential daytime noise criterion of 77 dBA range from approximately 100 to 300 feet.

Table 1.2-1 Construction Noise Projections at 50 feet for Alts. 1 and 2

Construction Equipment	Maximum Noise Level at 50 feet (dBA, slow)	Usage Factor	Pier Reconstruction and Ventilation Shaft Drilling	Jet Grouting	Utility Relocation	Cut and Cover Excavation	Construction of Ventilation Structures, Egresses and Elevator/Escalators
Air Compressor	80	40%	76	76	76	76	76
Generator (less than 25 KVA)	70	50%	67	67	67	67	67
Jack Hammer	85	20%			78		
Auger Drill Rig	85	20%	78				
Soil Mix Drill Rig (Jet Grouting)	80	50%		77			
Back Hoe	80	40%					76
Dump Truck	84	40%	80		80	83 b	
Crane	85	20%	75				75
Clam Shovel	93	20%				86	
Excavator	85	40%	81		81	81	
Hydraulically Powered Impact Device (Hoe Ram)	90	10%				80	
Concrete Mixer Truck	85	40%					81
Concrete Pump	82	20%					75
	Total Leq at 50 feet		86	80	85	89	84
	Total L10 at 50 feet		89	83	88	92	87
Distance to Impact for Typical Residential Daytime Criterion (L10 = 77 dBA) (feet) a			190	100	180	300	170

Source: HMMH, 2009.
a Front-row receptors without acoustic shielding.
b Two dump trucks assumed during construction.

1.2.2 Noise Impact Assessment

Potential airborne noise impact has been assessed for sensitive receptors. This section includes the results of this assessment for noise generated by transit operations and construction activities. All impacted receptors are shown in Figure 1.2-1.

1.2.2.1 Potential Impact from Transit Operations

Airborne noise impact is assessed at outdoor locations with frequent use such as balconies or park areas where passive recreation occurs. For receptors with no outdoor locations, impact is assessed at the nearest building façade. Potential noise impact from transit operations is assessed only at locations specified as sensitive by the FTA and does not include commercial or industrial land uses.

Since the proposed Project is an underground tunnel, airborne noise generated by the trains will not propagate significantly into the community. Airborne noise sources from transit operations include a TPSS at the “starter hole” location of the alignment (near Charles Street / MGH Station) and fans in ventilation shafts at the end of the northern and southern tail tracks, in the median of Cambridge Street at N. Anderson Street and near the eliminated or modified Bowdoin Station.

Ldn noise levels from the TPSS are projected to be less than 50 dBA at sensitive receptors and no impact is expected. Similarly, Ldn levels from ventilation shafts are projected to be less than 42 dBA and no impact is expected.

1.2.2.2 Potential Impact from Construction Activities

Potential noise impact from construction activities has been assessed at FTA Category 2 (residential, hotels, hospital beds) receptors for daytime, evening and nighttime periods and at institutional and commercial receptors for the daytime period. For short-term construction activities, a “worst case” scenario of potential noise impact without mitigation indicates that 26 residential properties and 26 institutional and commercial properties may be exposed to construction noise impact. The results of the construction noise impact assessment are shown in Tables 1.2-2 and 1.2-3. L10 construction noise levels are generally 80 to 90 dBA at these closest receptors (typical daytime criterion is 75 dBA for residences and 80 dBA for commercial land uses, typical evening criterion is 65 to 78 dBA at residences and typical nighttime criterion is 65 to 70 dBA at residences).

Table 1.2-2 Category 2 (Residential) Potential Construction Noise Impact for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)[a]	Side of Tracks	Minimum Distance to Const. (feet)	Const. Noise Level (L10)	Dominant Const. Method	Daytime Noise Limit (L10)	Evening Noise Limit (L10)	Nighttime Noise Limit (L10)	Impact Period
2	315 Cambridge St. (MF Res)	1+00	N	20	100	Cut & Cover	77	78	72	24 hour
6	Liberty Hotel	N3+00	N	175	82	Cut & Cover	75	65	65	Eve/Night
9	100 Cedar St. (MF Res)	S2+00	S	60	88	Cut & Cover	77	78	72	24 hour
10	98 Cedar St. (MF Res)	S2+00	S	90	84	Drilling	75	75	69	24 hour
11	96 Cedar St. (MF Res)	S2+00	S	120	82	Cut & Cover	75	73	66	24 hour
13	97 Cedar St. (MF Res)	S2+00	S	75	85	Cut & Cover	75	71	65	24 hour
14	95 Cedar St. (MF Res)	S2+00	S	100	81	Cut & Cover	75	69	65	24 hour
15	93 Cedar St. (MF Res)	S2+00	S	115	80	Cut & Cover	75	68	65	24 hour
16	91 Cedar St. (MF Res)	S2+00	S	130	79	Cut & Cover	75	66	65	24 hour
17	89 Cedar St. (MF Res)	S2+00	S	150	77	Cut & Cover	75	65	65	24 hour
19	3 Lindall Pl (MF Res)	1+00	S	100	81	Cut & Cover	75	71	65	24 hour
20	MGH (Yawkey Building)	2+00	N	142	73	Cut & Cover	75	65	65	Eve/Night
27	5 Grove St. (MF Res)	3+00	S	250	68	Cut & Cover	75	71	65	Night
28	6 Grove St. (MF Res)	3+00	S	200	65	Cut & Cover	75	68	65	Night
31	284 Cambridge St. (MF Res.)	4+00	S	40	94	Cut & Cover	77	78	72	24 hour
33	7 Anderson St. (MF Res)	5+00	S	40	94	Cut & Cover	75	71	65	24 hour
39	250 Cambridge St. (MF Res)	6+00	S	150	83	Cut & Cover	77	78	72	24 hour
42	1 Garden St. (MF Res)	7+00	S	225	79	Cut & Cover	77	78	72	24 hour
44	224 to 238 Cambridge St. (MF Res)	8+00	S	300	77	Cut & Cover	77	78	72	Night
45	Holiday Inn (5 Blossom St.)	8+00	N	350	76	Cut & Cover	75	73	66	24 hour
47	5 Hancock St. (MF Res)	14+00	S	500	69	Drilling	75	68	67	Eve/Night
49	14 Temple St. (MF Res)	17+00	S	200	67	Drilling	75	66	65	Eve/Night
50	16 Temple St. (MF Res)	17+00	S	220	66	Drilling	75	65	65	Eve/Night
51	9 Bowdoin St. (MF Res)	18+00	S	125	81	Drilling	75	66	65	24 hour
52	13 Bowdoin St. (MF Res)	18+00	S	125	81	Drilling	75	65	65	24 hour
53	10 Bowdoin St. (MF Res)	19+00	S	50	89	Drilling	75	70	69	24 hour
Total Number of Residential/Hospital Properties Exposed to Construction Noise Impact Without Mitigation										26

Source: HMMH, 2009.

a (N) is north tail track and (S) is south tail track station numbering.

Table 1.2-3 Category 3 (Institutional) and Commercial Potential Construction Noise Impact for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)[a]	Side of Tracks	Minimum Distance to Const. (feet)	Const. Noise Level (L10)	Dominant Const. Method	Daytime Noise Limit 7AM to 6PM (L10)
1	MEEI (325 Cambridge St. 3rd Floor Angiogenesis Lab)	1+00	N	20	100	Cut & Cover	80
7	CVS (155 Charles St.)	S0+00	S	25	95	Drilling	85
8	Top Shelf (161 Charles St.)	S1+00	S	80	85	Cut & Cover	85
12	Office (99 Cedar St.)	S2+00	S	30	97	Cut & Cover	80
18	Retail (326 Cambridge St.)	1+00	S	100	86	Cut & Cover	80
24	MGH Resident Physician's House (Office)	1+00	N	125	86	Cut & Cover	80
25	MGH Lawrence House (Offfice)	3+00	N	120	82	Cut & Cover	80
29	Grampy's Gas Station (296 Cambridge St.)	3+00	S	150	83	Cut & Cover	80
30	Antonios (286 Cambridge St.)	4+00	S	40	94	Cut & Cover	80
32	Fresco Boston Flowers	4+00	S	40	94	Cut & Cover	80
34	Pierrot	5+00	S	40	94	Cut & Cover	80
35	Finagle a Bagel	4+00	N	100	86	Cut & Cover	80
36	MGH Professional Office	5+00	N	50	92	Cut & Cover	80
37	White Hen Pantry	5+00	S	50	92	Cut & Cover	80
38	Discoveries Plus II	6+00	S	80	88	Cut & Cover	80
41	Mike's Movies	7+00	S	150	83	Cut & Cover	80
43	Exxon Gas Station	7+00	N	200	80	Cut & Cover	80
48	Old West Church (131 Cambridge St.)	16+00	N	400	71	Drilling	75
54	Cardinal Cushing Memorial Park	19+00	N	50	89	Drilling	75
55	Office (100 Cambridge St.)	22+00	S	110	86	Cut & Cover	80
56	Bright Horizons Daycare (100 Cambridge St.)	22+00	S	50	92	Cut & Cover	75
57	One Bowdoin Sq	20+00	N	115	85	Cut & Cover	80
58	New England Telegraph & Telephone	22+00	N	40	94	Cut & Cover	80
59	John F. Kennedy Federal Building	26+00	N	100	86	Cut & Cover	80
60	Boston City Hall Plaza	27+00	N	50	92	Cut & Cover	80
61	Center Plaza	27+00	S	40	94	Cut & Cover	80
Total Number of Institutional and Commercial Properties Exposed to Construction Noise Impact Without Mitigation							26

Source: HMMH, 2009.

a (N) is north tail track and (S) is south tail track station numbering.

1.2.3 Mitigation

Mitigation of airborne noise impact from construction activities is presented in this section.

1.2.3.1 Mitigation for Transit Operations

There is no potential airborne noise impact from transit operations and therefore no mitigation is required.

1.2.3.2 Mitigation for Construction Noise

Construction noise mitigation includes the preparation of a Noise Control Plan in conjunction with the contractor's specific equipment, schedule and methods of construction, maximum noise limits for each piece of equipment, prohibition on certain types of equipment during the nighttime hours and engineering noise control measures.

An Acoustical Engineer will prepare a Noise Control Plan in conjunction with the contractor's specific equipment and methods of construction. This Plan will be consistent with that specified in the CA/T 721.560 Noise Specification. Key elements to the Plan include:

- Identification of specific sensitive sites where noise monitoring will occur
- Background noise monitoring prior to and during construction
- Construction equipment noise certification testing
- Prohibition of impact pile-drivers during evening and nighttime hours (i.e. 6:00 PM to 10:00 PM and 10:00 PM to 7:00 AM)
- Prohibition of vibratory sheet pile driving and all impact devices including hoe rams, jackhammers and pavement breakers during nighttime hours
- Requirement for ambient-adjusting or manually adjusted backup alarms set to 5 dBA over background levels
- Truck idling limited to five minutes
- Acoustic shield requirement for jackhammers, chainsaws and pavement breakers
- Methods for projecting construction noise levels
- Detailed engineering noise control measures
- Methods for responding to community complaints
- Reporting of noise monitoring results, noise reduction measures used and responses to the community

Maximum noise limits for the following equipment that may be used during construction of the Red Line Blue Line Connector Project is shown in the table below.

A more complete list of construction noise equipment limits is provided in the Appendix.

Table 1.2-4 Construction Equipment Maximum Noise Limits

Construction Equipment	Maximum Noise Level at 50 feet (dBA, slow)
Air Compressor	80
Generator (less than 25 KVA)	70
Jack Hammer	85
Auger Drill Rig	85
Soil Mix Drill Rig (Jet Grouting)	80
Back Hoe	80
Dump Truck	84
Crane	85
Clam Shovel	93
Excavator	85
Hydraulically Powered Impact Device (Hoe Ram)	90
Concrete Mixer Truck	85
Concrete Pump	82

Source: CA/T Noise Specification 721.560

Noise control measures will be used to reduce noise emissions and potential impact to sensitive receptors. Many types of construction equipment include diesel engines which can be the most significant noise source. Therefore, reducing engine noise is often a key element to mitigating potential impact. Examples of such noise control measures include:

- Shields, shrouds or intake and exhaust mufflers
- Noise deadening materials adhered to chutes or storage bins
- Temporary noise barriers
- Acoustic enclosures
- Specialized back-up alarms
- Limiting the size of generators and the duration of their use
- Truck routes that minimize exposure to sensitive receptors

While some receptors such as residences, hospitals and hotels have increased sensitivity to noise during the nighttime and other receptors such as libraries, schools and commercial locations are not sensitive to activities during the night, a key element to mitigating potential noise impact is the scheduling of construction activities based on location.

1.2.4 Summary

There is no potential airborne noise impact from transit operations and no mitigation is required.

For short-term construction activities, a "worst case" scenario of potential noise impact without mitigation indicates that 26 residential properties and 26 institutional and commercial properties may be exposed to construction noise impact. These potential impacts can be mitigated with the preparation of a Noise Control Plan in conjunction with the contractor's specific equipment, schedule and methods of construction, maximum noise limits for each piece of equipment, prohibition on certain types of equipment during the nighttime hours and engineering noise control measures.

Vibration

The Secretary of Environmental Affairs Certificate on the Expanded Environmental Notification Form (EENF) requires that the Draft Environmental Impact Report (DEIR) analyze vibration for existing and proposed conditions consistent with U.S. Federal Transit Administration (FTA) guidelines. The Certificate requires that this analysis identifies the location of vibration-sensitive receptors, assesses the potential for vibration impact, specifies where mitigation is required, and which mitigation measures will be used.

The vibration impact analysis for the Project is based on the methodology defined in the U.S. Federal Transit Administration (FTA) guidance manual "*Transit Noise and Vibration Impact Assessment*" (Report FTA-VA-90-1003-06, May 2006). The analysis includes background on the vibration impact assessment methodology, existing vibration conditions, environmental consequences of the project including impact results for two proposed project alternatives, the type and location of specific measures required to mitigate potential vibration impacts and a summary of results.

This section describes the existing vibration conditions and environmental consequences along the proposed Red Line/Blue Line Connector Project including:

- Background information on ground-borne vibration and ground-borne noise
- Description of vibration-sensitive land use
- Identification of vibration-sensitive locations along the corridor
- Vibration impact criteria for transit operations and construction activities
- Measurement results of existing vibration conditions
- Vibration projection methodology
- Vibration impact assessment for transit operations and construction activities
- Recommended vibration mitigation
- Summary

1.3 Affected Environment

1.3.1 Introduction

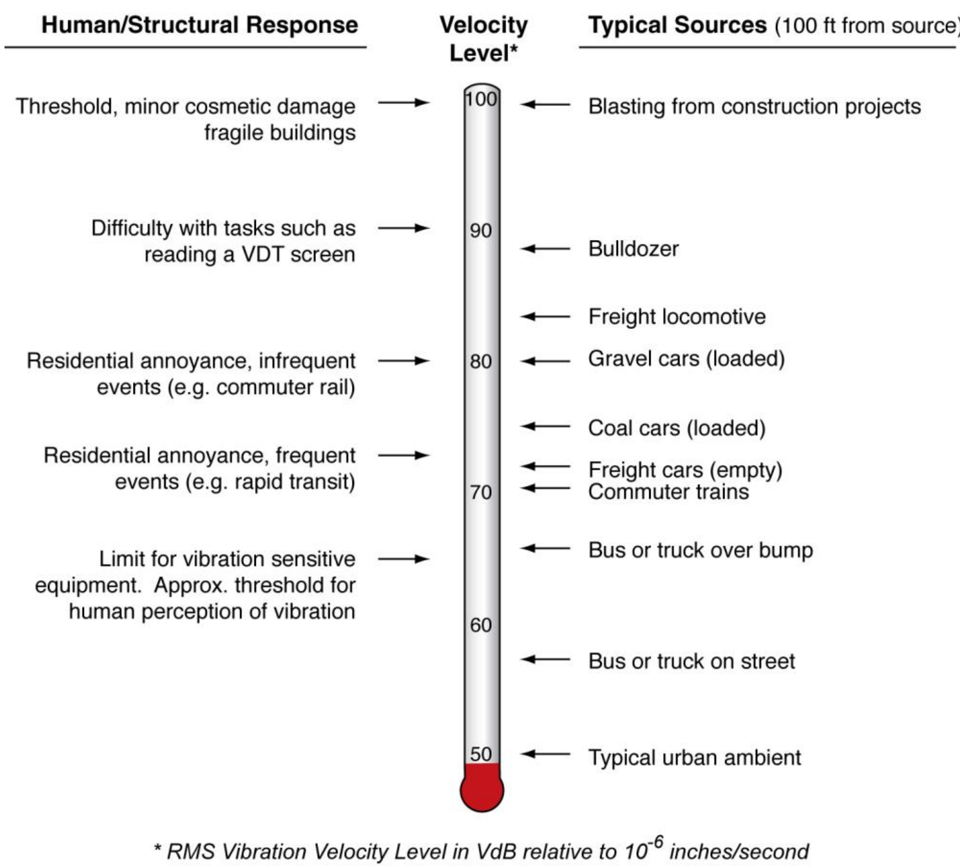
Ground-borne vibration is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity or acceleration. Because sensitivity to vibration typically corresponds to the vibration velocity amplitude in the low-frequency range of most concern for environmental

vibration (roughly 4 to 80 Hz), velocity is the preferred measure for evaluating ground-borne vibration from transit projects.

Ground-borne vibration is typically characterized in terms of the "smoothed" root-mean-square (RMS) vibration velocity level, in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels. Vibration levels expressed in terms of RMS velocity have been found to correlate most suitably to human response to vibration in buildings and are the metric commonly used in American and International standards.

Figure 1.3-1 illustrates typical ground-borne vibration levels for common sources as well as criteria for human and structural response to vibration. As shown, the range of interest is from approximately 50 to 100 VdB, from imperceptible background vibration to the threshold of damage. Although the approximate threshold of human vibration perception is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.

Figure 1.3-1 Typical Ground-Borne Vibration Levels and Criteria



Source: Harris Miller Miller & Hanson, 2009

Ground-borne noise is produced when ground-borne vibrations propagate into a building and radiate noise from the motion of the room surfaces. The room surfaces are essentially acting like a giant loudspeaker from the vibrations. Ground-borne noise is perceived as a low frequency rumble and is generally considered only when airborne paths are not present (e.g. train inside a tunnel or a large masonry building with no windows or other openings to the outdoors).

1.3.2 Vibration-Sensitive Land Use Categories

The FTA generally classifies vibration-sensitive land uses into the same three categories as noise. Although commercial and industrial land uses are sensitive to daytime construction noise, they are not considered to be sensitive to potential annoyance from vibrations generated during construction or transit operations. All structures including those specified by FTA as vibration-sensitive, commercial and industrial buildings are assessed for potential damage due to transit operations and construction activities.

There are some buildings, such as television studios, concert halls, recording studios and theaters that can be very sensitive to vibration. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Some buildings such as medical facilities or research institutions may contain vibration-sensitive equipment. Potential vibration impact of sensitive equipment such as electron microscopes and magnetic resonance imaging scanners is also considered.

- **Vibration Category 1 – High Sensitivity**: Included in this category are buildings where vibration would interfere with operations. Vibration levels may be well below those associated with human annoyance. These buildings include vibration-sensitive research and manufacturing facilities, hospitals with sensitive equipment and university research operations. The sensitivity to vibration is dependent on the specific equipment present. Some examples of sensitive equipment include scanning electron microscopes, magnetic resonance imaging scanners and lithographic equipment.
- **Vibration Category 2 - Residential**: Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels.
- **Vibration Category 3 - Institutional**: This category includes buildings with primarily daytime and evening use. This category includes schools, libraries and churches.
- **Special Buildings**: Special-use buildings such as television studios, concert halls, recording studios, auditoriums and theatres warrant special consideration. Potential ground-borne vibration and ground-borne noise impact is assessed at these buildings.

1.3.2.1 Vibration-Sensitive Land Use

Vibration-sensitive land use in the proposed Red Line/Blue Line Connector Project Study Area was identified primarily during field visits with supplemental information provided by personnel at MGH and MEEI identifying examples of vibration-sensitive equipment at the hospitals.

Land use which is sensitive to vibration from transit operations and construction activities includes multi-family residential properties, hotels, hospitals, schools, a television studio, a library, a church, a museum and a fire department with housing. Humans within commercial and industrial land uses are not considered to be sensitive to vibration impact for potential annoyance. All structures in close proximity to the Project are sensitive to potential structural damage from vibrations.

<u>From Western Terminus to Blossom Street</u>

Residential properties in this section of the alignment include buildings on Cambridge Street and buildings on Cedar Street, Lindall Place, Grove Street, Strong Place, Anderson Street and Garden Street which are generally set back further from Cambridge Street.

The MGH campus and MEEI are in this section of the alignment. Examples of the closest vibration-sensitive equipment to the Project include imaging scanners such as MRI’s and CT scanners, microscopes and laser-based equipment. The buildings which house these instruments include the Yawkey building, which is approximately 100 feet from the proposed alignment, the Northeast Proton Therapy Center, which is approximately 300 feet from the proposed alignment and other buildings such as Wang, Barlett, Barlett Extension, Ellison, White and Founders, which are generally 400 to 700 feet from the proposed alignment. MEEI is located at the corner of Charles Street and Fruit Street which is approximately 450 feet from the proposed alignment. The MEEI Angiogenesis Lab at 325 Cambridge Street contains a 100x magnification microscope and this building is located approximately 10 feet (distance at-grade) from the construction “starter hole” location.

<u>Blossom Street to New Chardon Street</u>

This section of the alignment includes multi-family residential buildings on the south side of Cambridge Street and buildings on Irving Street, Russell Street, Joy Street, Hancock Street, Ridgeway Lane and Temple Street which are set back further from Cambridge Street. The Boston Fire Department District 3 Ladder 24, which includes housing for the firefighters, is located in this area. Other sensitive locations include the Holiday Inn, MGH Simches building, the Boston Public Library West End Branch, a nursery school on Joy Street, the Otis House Museum and the Old West Church.

New Chardon Street to Eastern Terminus

In this section of the alignment there are several multi-family residential buildings on Cambridge Street between Temple Street and Bowdoin Street including residential properties at 100 Cambridge Street. Other vibration-sensitive land use in this section includes the WHDH/WLVI Television Studio and a daycare at 100 Cambridge Street.

1.3.3 Vibration Impact Criteria

1.3.3.1 Criteria for Human Annoyance and Sensitive Equipment

The FTA vibration impact criteria for transit operations are based on land use and train frequency, as shown in Table 1.3-1. There are separate FTA criteria for ground-borne noise, the "rumble" that can be radiated from the motion of room surfaces in buildings due to ground-borne vibration. Such criteria are particularly important for underground transit operations when airborne noise paths are not dominant.

For special buildings such as television studios, concert halls, recording studios and theaters that can be very sensitive to vibration, special ground-borne vibration and ground-borne noise criteria apply as listed in Table 1.3-2.

In addition to the ground-borne vibration criteria provided in Tables 1.3-1 and 1.3-2 for assessing overall ground-borne noise and vibration levels, FTA has established criteria in terms of one-third octave band frequency spectra for use in detailed analyses. Table 1.3-3 and Figure 1.3-2 show the more detailed vibration criteria and the description of their use. These are particularly useful for assessing potential ground-borne vibration impact to sensitive equipment.

For residential buildings with nighttime occupancy, the applicable ground-borne vibration criterion for Blue Line trains or construction activities is a maximum velocity level of 72 VdB, measured in any one-third octave band over the frequency range from 4 Hz to 80 Hz. The applicable ground-borne noise criterion for residences and hospital beds is 35 dBA

For institutional buildings such as schools, libraries, museums and churches, the applicable ground-borne vibration criterion for Blue Line trains or construction activities is 75 VdB measured in any one-third octave band over the frequency range from 4 Hz to 80 Hz. The applicable ground-borne noise criterion for institutional buildings is 35 dBA.

For the WHDH/WLVI television studios at 7 Bulfinch Place, the applicable criteria are a ground-borne vibration level of 65 VdB and a ground-borne noise level of 25 dBA.

For vibration-sensitive equipment at MGH and MEEI, ground-borne vibration criteria depend on the specific instruments and their location within the buildings. At MGH, vibration-sensitive equipment includes imaging instruments such as MRI's and CT scanners, nuclear magnetic resonance spectroscopy, microscopes, laser-based systems and operating rooms. At MEEI, vibration-sensitive equipment includes MRI's, laser-based systems for eye surgery and operating rooms. In this analysis, an investigation has been made based on comparing the existing vibration levels near the sensitive equipment to the projected vibration levels to determine if there would be any considerable increase over ambient levels.

Table 1.3-1 FTA Ground-Borne Noise and Vibration Impact Criteria

	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)			Ground-Borne Noise Impact Levels (dBA re 20 micro-pascals)		
Land Use Category	**Frequent Events[1]**	**Occasional Events[2]**	**Infrequent Events[3]**	**Frequent Events[1]**	**Occasional Events[2]**	**Infrequent Events[3]**
Category 1: Buildings where low ambient vibration is essential for interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	n/a[5]	n/a[5]	n/a[5]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Source: FTA, 2006.
1 "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.
2 "Occasional Events" is defined as between 30 and 70 vibration events of the same kind per day.
3 "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day.
4 This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5 Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

Table 1.3-2 FTA Ground-Borne Noise and Vibration Impact Criteria for Special Buildings

	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-Borne Noise Impact Levels (dBA re 20 micro-pascals)	
Type of Building or Room[3]	**Frequent Events[1]**	**Occasional or Infrequent Events[2]**	**Frequent Events[1]**	**Occasional or Infrequent Events[2]**
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theatres	72 VdB	80 VdB	35 dBA	43 dBA

Source: FTA, 2006.

1 "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

2 "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day.

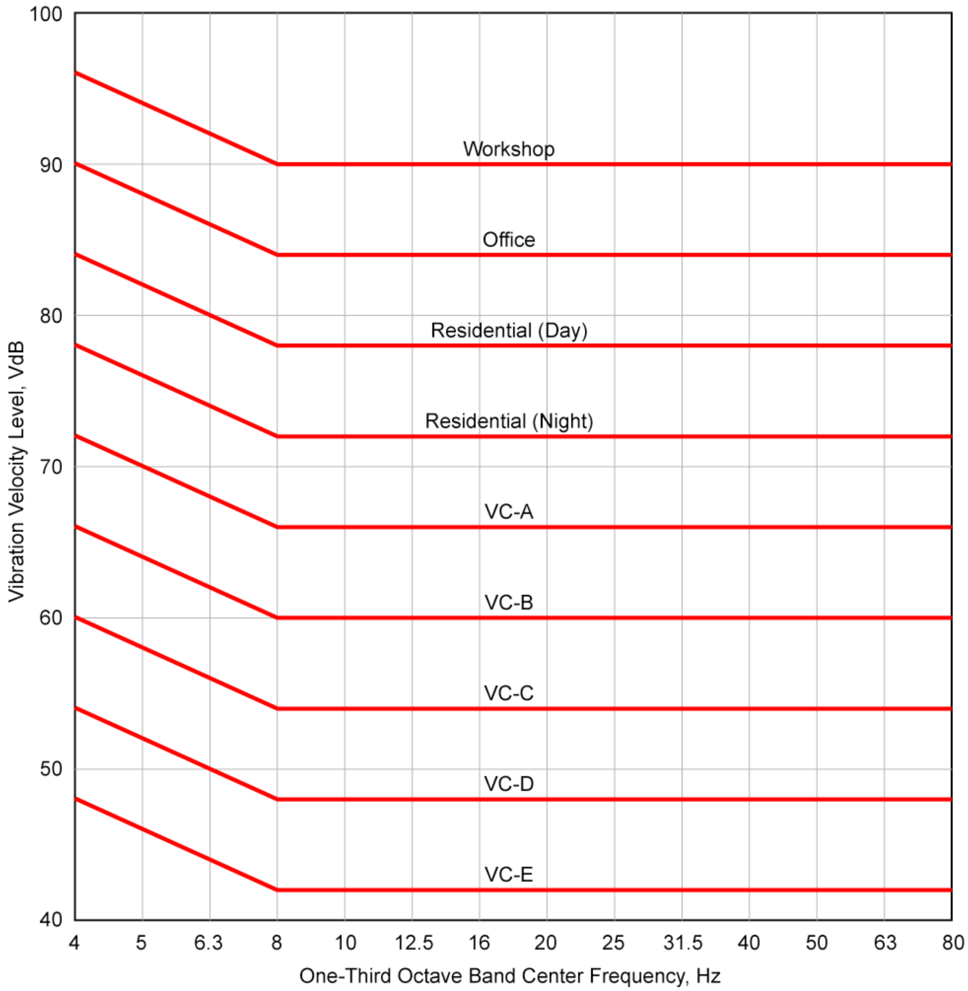
3 If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 pm, it should be rare that the trains interfere with the use of the hall.

Table 1.3-3 Vibration Criteria for Detailed Analysis

Criterion Curve	Maximum Vibration Level (VdB re 1 micro-inch/sec)	Description of Use
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X)
Residential Night, Operating Rooms	72	Vibration not feelable, but ground-borne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment
VC-B	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths
VC-C	54	Appropriate for most lithography and inspection equipment to 1 micron detail size
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment

Source: FTA, 2006.

Figure 1.3-2 Criteria for Detailed Vibration Analysis



1.3.3.2 Criteria for Potential Vibration Damage to Structures

In addition to ground-borne vibration criteria for humans in residential, institutional and special buildings and vibration-sensitive equipment, there are ground-borne vibration criteria for potential damage to structures. The limits of vibration that structures can withstand are substantially higher than those for humans and for sensitive equipment. Table 1.3-4 presents guidelines for assessing the potential for vibration damage to structures based on the type of building construction. This table includes root-mean square (RMS) vibration levels in VdB reference to 1 micro-inch per second and peak-particle velocity levels in inches per second. A crest factor of four, representing a difference of 12 decibels between peak and RMS is used in this table. Since buildings in the study area are typically engineered concrete and

masonry or reinforced-concrete, steel or timber construction, a vibration damage criterion of 98 VdB has been used to asses potential impact. It should be noted that these criteria are more conservative than other standards such as the U.S. Bureau of Mines frequency-dependent vibration criteria which is equivalent to approximately 114 VdB at 40 Hz and above.

Table 1.3-4 Construction Vibration Damage Criteria

Building Category	Ground-Borne Vibration Level (VdB) and Peak-Particle Velocity Equivalent (in/sec)
Reinforced-concrete, steel or timber	102 VdB (0.5 in/sec)
Engineered concrete and masonry	98 VdB (0.3 in/sec)
Non-engineered timber and masonry buildings	94 VdB (0.2 in/sec)
Buildings extremely susceptible to vibration damage	90 VdB (0.12 in/sec)

Source: FTA, 2006.

Since the exact location of construction equipment is critical to projecting vibration levels, a more detailed assessment of potential vibration damage will be performed during final design including more accurate equipment locations. Please note that these criteria do not address potential damage to structures due to soil settlement or displacement caused by construction activities.

1.3.4 Existing Vibration Conditions

This section discusses the existing vibration levels and vibration-sensitive land uses in the Study Area.

1.3.4.1 Vibration Measurement Methodology

Vibration measurements used to project future vibration levels included reference vibration velocity levels of Blue Line trains operating between Government Center and Bowdoin Stations, bore-hole vibration propagation measurements conducted by HMMH in a prior study of this corridor, and ambient vibration levels measured near sensitive equipment at MGH and MEEI.

All vibration measurements were conducted using accelerometers mounted in the vertical direction. The signals were recorded with a multi-channel digital recorder and then processed in the laboratory using digital signal processing software.

1.3.4.2 Existing Vibration Measurement Results

Reference vibration measurements of the Blue Line Trains were conducted (2009) at station number 26+00 near the John F. Kennedy Federal Building at 15 New Sudbury Street. Blue Line trains were traveling at approximately 15 mph at this location and measurements were conducted of trains on both the near track and far track locations. Accelerometers were located approximately 35 feet, 38 feet and 55 feet (slant distance) from the near track centerline.

Bore-hole vibration propagation measurements were conducted (1986) at four locations throughout the Study Area[1]. These measurements are conducted by boring a hole down to several depths and producing a vibration impulse by dropping a 140-pound weight (soil sampling hammer) from 18 inches. The vibration response is then measured with accelerometers located on top of the soil at various distances set back from the hole. These measurements of point source transfer mobility are then integrated along the length of a train to calculate the line source transfer mobility. The line source transfer mobility provides information about the efficiency that vibrations propagate in the soil according to vibration frequency.

The soil conditions throughout the project are relatively similar in regard to vibration propagation. Bedrock is typically 20 feet below the tunnel depth which is typically 60 feet. The soil generally consists of miscellaneous fill on top of silty clay and glacial till.

Ambient vibration measurements were conducted (2009) at nine locations throughout MGH and MEEI at vibration-sensitive equipment locations closest to the proposed alignment. Unlike noise criteria which typically depend on existing noise conditions, vibration criteria do not depend on existing vibration levels. However, an investigation of potential impact to vibration-sensitive equipment has been made based on comparing the existing vibration levels near the sensitive equipment to the projected vibration levels from transit operations and construction. Figures showing the average ambient vibration levels measured at MGH and MEEI are presented in the Appendix.

A summary of all vibration measurement locations is shown in Table 1.3-5. Noise and vibration measurement locations are shown in Figure 1.1-4.

[1] HMMH, 1987. Noise and Vibration Conditions Reports Bowdoin/Charles Connector Project. Report No. 260360 Prepared for Howard Needles Tammen & Bergendoff and MBTA by Harris Miller Miller & Hanson Inc..

Table 1.3-5 Vibration Measurement Results

Measurement Site	Location	Type of Measurement	Results
V-1	John F. Kennedy Federal Building	Reference Vibration Levels of Blue Line Trains	Maximum Vibration Velocity at 50 feet (slant distance) 60 to 70 VdB primarily between 40 and 80 Hz
V-2	North Side of Cambridge Street, 10 feet East of Lynde Street	Bore Hole Vibration Propagation a	See Appendix
V-3	South Edge of Cambridge Street, 20 feet East of Hancock Street	Bore Hole Vibration Propagation a	See Appendix
V-4	Northwest Corner of Cambridge Street and Blossom Street	Bore Hole Vibration Propagation a	See Appendix
V-5	Northeast Corner of Cambridge Street and Grove Street	Bore Hole Vibration Propagation a	See Appendix
V-6	MGH (Simches 8th floor Room 8151 Laser-Based Systems)	Ambient	Meets VC-C Criterion a
V-7	MGH (Simches 7th floor Room 7502 NMR)	Ambient	Meets VC-B Criterion a
V-8	MGH (Barlett Extension 6th floor Room 620 Imaging Equipment)	Ambient	Meets VC-B Criterion a
V-9	MGH (Ellison 2nd floor Room 230 MRI Suite)	Ambient	Meets VC-C Criterion a
V-10	MGH (Yawkey 10th floor Room 10.748 Embryology Lab)	Ambient	Meets VC-B Criterion a
V-11	MEEI (325 Cambridge Street Outside Building)	Ambient	Meets VC-E Criterion a
V-12	MGH (Yawkey 6th floor Room 6.428 MRI Suite)	Ambient	Meets VC-C Criterion a
V-13	MEEI (1st floor MRI Suite)	Ambient	Meets VC-E Criterion a
V-14	MEEI (12th floor Ophthalmic Surgery Equipment)	Ambient	Meets VC-C Criterion a

Source: HMMH, 1986 and 2009
a Average ambient vibration levels are compared to VC criteria.

1.4 Environmental Consequences

1.4.1 Ground-Borne Vibration and Ground-Borne Noise Projections

The methodology for projecting ground-borne noise and vibration from transit operations and construction activities is presented in this section.

1.4.1.1 Transit Operations

The methodology for projecting ground-borne vibration and ground-borne noise includes conducting reference vibration measurements of Blue Line trains, conducting measurements of the vibration propagation characteristics of the soil along the proposed corridor, projecting future vibration levels from the proposed Project, assessing potential impact and determining the need, feasibility and reasonableness of mitigation recommendations.

Future vibration levels at sensitive receptors depends primarily on the proximity to the proposed alignment (slant distance for the tunnel alignment), the type of building construction, the floor of the building where vibrations are projected, the speed of the trains and the presence of any special trackwork or other gaps in the rail running surface (i.e. crossovers, turnouts or jointed rail).

The Blue Line train force density was calculated based on the reference vibration measurements conducted between Government Center and Bowdoin Stations (V-1) and the line source transfer mobility measured at bore-hole vibration propagation site V-2. Future vibration levels of the Blue Line trains including adjustments for building coupling, train speed and track conditions. Blue Line trains are currently running on jointed track at this site and continuously-welded rail will be used for the Project, so a five decibel reduction has been made to the measured levels to account for the elimination of the gaps in the jointed track.

The relationship between vibration level, vehicle force density and line source transfer mobility is shown in the following equation:

Lv (receptor location) = FD + TM + C + S + T

where;

FD = Blue Line Train Force Density

TM = Line Source Transfer Mobility (Soil Propagation Characteristics)

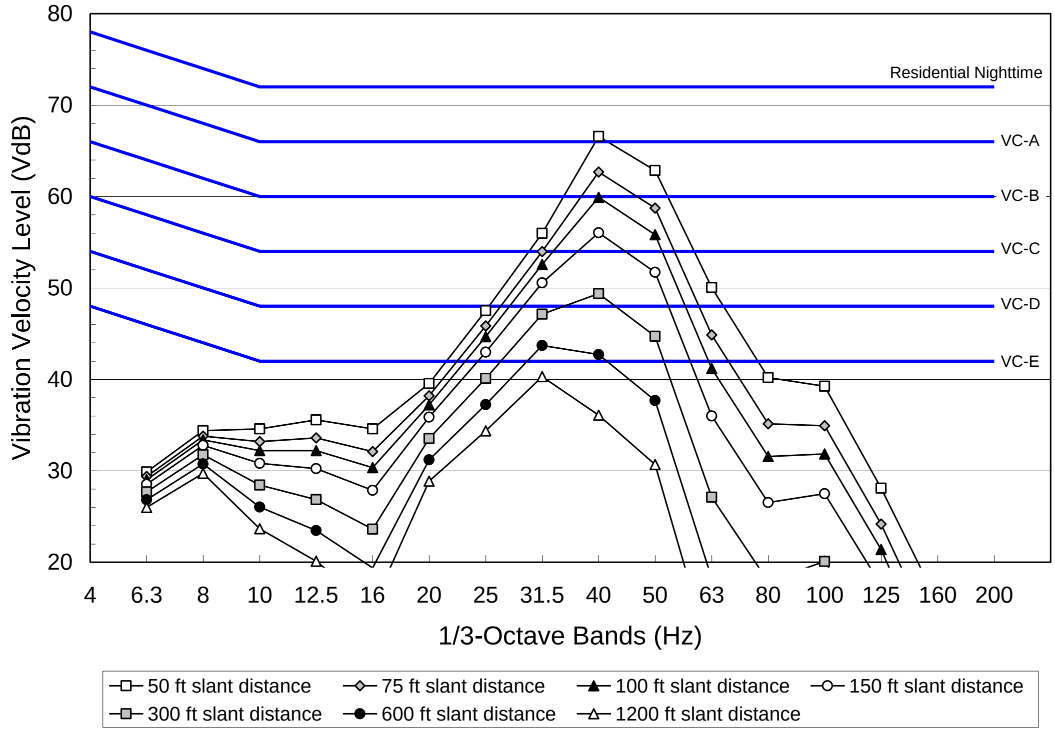
C = Building coupling factors (construction type, floor)

S = Speed factor 20*Log(train speed/force density train speed)

T = track condition adjustment (jointed rail, continuously-welded rail or special trackwork)

The resulting Blue Line train vibration levels as a function of distance are shown in Figure 1.3-3. This figure shows that even at a slant distance of 50 feet from the near track centerline vibration levels are projected to be well below the residential nighttime criterion of 72 VdB. As the distance to the near track centerline increases, the projected vibration levels decrease. The average measured Blue Line train vibration levels, Blue Line train force density at 15 mph on continuously-welded rail and projected vibration levels for transit operations at all sites are presented in the Appendix.

Figure 1.3-3 Projected Blue Line Train Vibration Levels at Site V-5



Ground-borne noise projections are focused on noise generated by vibration from transit operations, and the tunnel boring machine and muck trains during construction. Ground-borne noise for other above-grade construction activities that generate vibration, such as jackhammers or hoe rams, is not considered since airborne noise paths would dominate in these situations. Ground-borne noise is calculated from the vibration results by applying the A-weighting to the vibration velocity levels and summing the overall level.

1.4.1.2 Construction Activities

Only in very rare instances do vibrations generated by transit operations pose any risk of damage to nearby structures. Typically, the only potential risk of vibrations causing damage to nearby structures is from certain construction activities at very close distances. The most significant construction activities for which potential damage is assessed include clam shovel drops, caisson drilling, loaded trucks, hoe rams, and jackhammers. Although construction vibrations are only temporary, it is still reasonable to assess the potential for human annoyance and damage.

Source vibration levels at 25 feet and the distances to potential residential annoyance (72 VdB criterion) and potential damage (98 VdB criterion) are presented for these construction equipment in Table 1.3-6.

Source levels for a tunnel boring machine (TBM) in soil and muck trains used to remove excavate from the bored or mined tunnels are presented in this table for either efficient or inefficient soil propagation. While higher vibration levels could be expected for tunnel boring in rock, boring is not expected to occur in bedrock which is 20 to 40 feet below the typical tunnel depth of approximately 60 feet.

Table 1.3-6 Vibration Source Levels for Construction Equipment

Equipment	Ground-Borne Vibration Level (VdB) at 25 feet	Distance to Potential Annoyance (72 VdB Criterion) (feet)	Distance to Potential Damage (98 VdB Criterion) (feet)
Clam Shovel (drop)	94	135	18
Hoe Ram	87	79	11
Caisson Drilling	87	79	11
Loaded Trucks	86	73	10
Jackhammer	79	43	6
Tunnel Boring Machine (in soil with inefficient propagation)	69	13	2
Tunnel Boring Machine (in soil with efficient propagation)	79	27	4
Muck Trains (in soil with inefficient propagation)	70	16	2
Muck Trains (in soil with efficient propagation)	80	27	4

Source: FTA, 2006 and HMMH, 2009.

Vibrations from construction activities are projected at nearby buildings according to the following equation:

Lv (receptor location) = Lv (25 feet) – 30*Log(distance to receptor/25)

Table 1.3-6 shows that potential damage to nearby structures will not occur beyond 11 feet for most equipment. Dropping a clam shovel within 18 feet of nearby buildings may generate vibration levels that can cause damage. Distance to potential annoyance is less than 80 feet for a hoe ram, caisson drilling and loaded trucks, 43 feet from a jackhammer and 135 feet from a clam shovel drop.

For boring and mining activities, the distance to potential building damage (98 VdB criterion) from the TBM or muck trains is four feet or less and the distances to potential annoyance (72 VdB criterion) are approximately 27 feet in efficient soil and 16 feet or less in inefficient soil.

1.4.2 Ground-Borne Vibration Impact Assessment

Potential ground-borne vibration impact has been assessed for sensitive receptors. This section includes the results of this assessment for vibrations generated by transit operations and construction activities. All impacted receptors are shown in Figure 1.2-1.

1.4.2.1 Potential Impact Transit Operations

There is no potential ground-borne vibration impact from transit operations to residences, hotels, hospital beds or institutional land uses. As shown in Table 1.3-7, Ground-borne vibration from transit operations at vibration-sensitive equipment at MGH and MEEI is expected to be below the VC-E criterion at all locations except for the MEEI Angiogenesis Lab at 325 Cambridge Street where vibrations from transit operations are projected to be below the VC-C criterion.

Since existing vibration levels at sensitive equipment is typically at VC-B or VC-C levels, transit operations are not expected to cause any adverse effect. The sensitive equipment at the Angiogenesis Lab is a 100x magnification microscope which typically will only require vibration levels to be below the residential nighttime/operating room criterion (72 VdB) to avoid impact. Interior vibration levels at the 3rd floor of this building are projected to be 54 VdB and well below this impact criterion.

Ground-borne noise, which is produced when ground-borne vibration propagates into a building and radiates noise from the motion of the room surfaces, has been assessed at sensitive locations along the project for transit operations. Ground-borne noise levels are projected to be 35 dBA or less at sensitive receptors that are further than 100 feet (slant distance) from the double crossover between station number 4+00 and 8+00 and no impact is projected. At locations within 100 feet of this double crossover, ground-borne vibration levels and ground-borne noise levels are 10 decibels higher than on straight tangent track due to the gaps in the rail running surface at the crossover points and frogs. As shown in Table 1.3-8, ground-borne noise levels are between 35 and 41 dBA (residential criterion is 35 dBA) at these locations.

Table 1.3-7 Projected Ground-Borne Vibration Levels at Sensitive Equipment from Transit Operations for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)[a]	Side of Tracks	Slant Distance to Near Track Tunnel Centerline (feet)	Train Speed (mph)	Maximum Vibration Velocity Level in any 1/3-Octave Band from 4 to 80 Hz (VdB)	Meets General Vibration Criterion
1	MEEI (325 Cambridge St. 3rd Floor Angiogenesis Lab)	1+00	North	57	10	54	VC-C
3	MEEI (1st floor MRI Suite)	N0+00	North	477	10	32	VC-E
4	MEEI (12th floor Opthalmic Laser Equipment)	N0+00	North	502	10	24	VC-E
5	MGH (MRI Trailer Outside Founders Building)	N0+00	North	502	10	31	VC-E
20	MGH (Yawkey 6th floor MRI Suite)	1+00	North	120	10	42	VC-E
21	MGH (Northeast Proton Therapy Center 1st floor)	1+00	North	324	10	35	VC-E
22	MGH (Ellison 2nd floor MRI Suite)	N0+00	North	702	10	33	VC-E
23	MGH (Yawkey 10th floor Embryology Lab)	1+00	North	393	10	27	VC-E
26	MGH (Wang Building 1st floor)	2+00	North	403	10	33	VC-E
40	MGH (Barlett Extension 6th floor Imaging Equipment)	7+00	North	433	12	31	VC-E
46	MGH (Simches 7th floor NMR Spectrometer)	10+00	North	254	15	38	VC-E

Source: HMMH, 2009.
a (N) is north tail track and (S) is south tail track station numbering.

Table 1.3-8 Category 2 (Residential) Potential Ground-Borne Noise Impact from Transit Operations for Alternatives 1 and 2

Receptor Number	Location	Station No. (00+00)	Side of Tracks	Slant Distance to Near Track Tunnel Centerline (feet)	Train Speed (mph)	Slant Distance to Crossover (feet)	Ground-Borne Noise Level (dBA)
31	284 Cambridge St. (MF Res.)	4+00	S	57	10	57	35
39	250 Cambridge St. (MF Res)	6+00	S	57	11	63	39
42	1 Garden St. (MF Res)	7+00	S	57	12	57	36
44	224 to 238 Cambridge St. (MF Res)	8+00	S	57	13	98	41

Source: HMMH, 2009.

1.4.2.2 Potential Impact from Construction Activities

Potential damage to nearby structures from construction activities is projected at a multi-family residential building at 315 Cambridge Street and a MEEI building at 325 Cambridge Street without mitigation as shown in Table 1.3-9. These buildings are expected to be approximately 10 feet away from the construction "starter hole" where a clam shovel may be used for cut and cover excavation and drilling for jet grouting the adjacent soil. The vibration level at the ground of these buildings from a clam shovel dropping at 10 feet is projected to be 106 VdB and from drilling is 99 VdB. This assessment does not include any potential damage to structures due to soil settlement or displacement caused by construction activities.

Potential human annoyance from short-term construction vibration activities is projected at five sensitive receptors including the Angiogenesis Lab at 325 Cambridge Street and multi-family residences as shown in Table 1.3-10. The primary construction equipment of concern at these locations is the clam shovel used during cut and cover excavation and drilling for jet grouting the adjacent soil. Interior vibration levels are projected to be 73 to 100 VdB at these locations. No ground-borne noise impact is projected from either the tunnel boring machine or muck trains.

Table 1.3-9 Potential Vibration Damage to Structures from Construction Activities for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)	Side of Tracks	Distance to Construction (feet)	Construction Equipment	Potential Damage Criterion (VdB)	Maximum Ground Vibration Velocity from Construction Equipment (VdB)
1	MEEI (325 Cambridge St. 3rd Floor Angiogenesis Lab)	1+00	N	10	Clam Shovel/ Drilling	98	106/ 99
2	315 Cambridge St. (MF Res)	1+00	N	10	Clam Shovel/ Drilling	98	106/ 99
Total Number of Structures Potentially Exposed to Vibration Damage from Construction Activities Without Mitigation							2

Source: HMMH, 2009.

Table 1.3-10 Potential Vibration Impact (Annoyance) from Construction Activities for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)[a]	Side of Tracks	Distance to Construction (feet)	Construction Equipment	Annoyance Criterion (VdB)	Maximum Interior Vibration Velocity (VdB)
1	MEEI (325 Cambridge St. 3rd Floor Angiogenesis Lab)	1+00	N	10	Clam Shovel	75	100
2	315 Cambridge St. (MF Res)	1+00	N	10	Clam Shovel	72	100
9	100 Cedar St. (MF Res)	S2+00	S	80	Clam Shovel	72	73
31	284 Cambridge St. (MF Res.)	4+00	S	40	Clam Shovel	72	82
33	7 Anderson St. (MF Res)	5+00	S	40	Clam Shovel	72	78
Total Number of Residences Potentially Exposed to Vibration Impact (Annoyance) from Construction Activities							5

Source: HMMH, 2009.
a (N) is north tail track and (S) is south tail track station numbering.

The potential for short-term construction vibration impact on vibration-sensitive equipment at MGH and MEEI has also been assessed for the clam shovel and drilling. At most sensitive equipment at MGH and MEEI, vibration levels from construction activities will be below existing levels. The vibration projections are shown in Table 1.3-11. Please note that this table only presents projected vibration levels at the sensitive equipment and does not imply that impact will occur at these locations.

At three locations, vibrations from construction activities may temporarily result in vibration levels above the existing vibration levels. At the main MEEI building at 243 Charles Street, construction vibration levels (47 VdB) are expected to be below VC-D criterion while existing vibration levels meet VC-E criterion (42 VdB). At the MGH Yawkey building 6th floor MRI, construction vibration levels (58 VdB) are expected to be below VC-B criterion while existing vibration levels meet VC-C criterion (54 VdB). Although vibration levels from construction may increase slightly over the existing at these two locations, they are still relatively low and not expected to cause any adverse effect to the MRI's at these locations. At the MEEI Angiogenesis Lab at 325 Cambridge Street, construction vibration levels (98 VdB) are projected to exceed the operating room general criterion (72 VdB).

Table 1.3-11 Projected Ground-Borne Vibration Levels at Sensitive Equipment from Construction Activities for Alts. 1 and 2

Receptor Number	Location	Station No. (00+00)[a]	Side of Tracks	Distance to Construction (feet)	Construction Equipment	Maximum Interior Vibration Velocity (VdB)	Meets General Vibration Criterion
1	MEEI (325 Cambridge St. 3rd Floor Angiogenesis Lab)	1+00	N	10	Clam Shovel	98	Over VC-A
3	MEEI (1st floor MRI Suite)	N0+00	N	425	Clam Shovel	47	Meets VC-D
4	MEEI (12th floor Opthalmic Laser Equipment)	N0+00	N	549	Clam Shovel	37	Meets VC-E
5	MGH (MRI Trailer Outside Founders Building)	N0+00	N	708	Clam Shovel	40	Meets VC-E
20	MGH (Yawkey 6th floor MRI Suite)	1+00	N	142	Clam Shovel	58	Meets VC-B
21	MGH (Northeast Proton Therapy Center 1st floor)	1+00	N	350	Clam Shovel	50	Meets VC-C
22	MGH (Ellison 2nd floor MRI Suite)	N0+00	N	743	Clam Shovel	44	Meets VC-D
23	MGH (Yawkey 10th floor Embryology Lab)	1+00	N	407	Clam Shovel	41	Meets VC-E
26	MGH (Wang Building 1st floor)	2+00	N	531	Clam Shovel	44	Meets VC-D
40	MGH (Barlett Extension 6th floor Imaging Equipment)	7+00	N	496	Clam Shovel	42	Meets VC-D
46	MGH (Simches 7th floor NMR Spectrometer)	10+00	N	620	Clam Shovel	38	Meets VC-E

Source: HMMH, 2009.
a (N) is north tail track and (S) is south tail track station numbering.

1.4.3 Ground-Borne Vibration Mitigation

To mitigate potential ground-borne noise impact from transit operations at residences in close proximity to the double crossover, use of spring-rail frogs, moveable-point frogs or flange-bearing frogs will eliminate the impact at this location.

The MEEI building at 325 Cambridge Street and the multi-family residential building at 315 Cambridge Street may potentially be exposed to vibrations from construction activities which could cause damage, annoy humans within the buildings and affect vibration-sensitive equipment in the Angiogenesis Lab without mitigation. To mitigate these potential impacts, the contractor will need to use specific construction methods and equipment to minimize the potential for damage, annoyance or affects on sensitive equipment. Such methods may involve not using a clam shovel for excavation, not using a typical drill rig prior to jet grouting or using a particular drill rig which generates lower vibrations. Given the close proximity of the construction activities to the building, other mitigation measures such as trenches or wave barriers are likely infeasible.

1.4.4 Summary

Ground-borne vibration impact from transit operations and construction activities has been assessed for potential damage to structures, potential annoyance to humans in residential and institutional buildings and potential affect to vibration-sensitive equipment.

There is no potential ground-borne vibration impact from transit operations to residences, hotels, hospital beds or institutional land uses. Ground-borne vibration at vibration-sensitive equipment at MGH and MEEI is expected to be below the VC-E criterion from transit operations and below existing levels for construction activities at most locations. One exception is the MEEI Angiogenesis Lab at 325 Cambridge Street where vibrations from transit operations are projected to be below the VC-C criterion and vibrations from construction activities without mitigation may be high enough to cause structural damage.

Potential damage to nearby structures from construction activities is projected at a multi-family residential building at 315 Cambridge Street and a MEEI building at 325 Cambridge Street without mitigation. Potential human annoyance from short-term construction vibration activities is projected at a total of five sensitive receptors. To mitigate these potential impacts, the contractor will need to use specific construction methods and equipment to minimize the potential for damage, annoyance or affect to equipment.

Figures

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Appendices

Appendices include the following:

- Table of Construction Equipment Noise Limits and Usage Factors
- Hourly Noise Measurement Result (Long-Term Sites)
- Ambient L50 Vibration Spectra at MGH
- Ambient L50 Vibration Spectra at MEEI
- Vibration Levels of Blue Line Trains between Government Center and Bowdoin Stations
- Blue Line Train Force Density Level at 15 mph on continuous-welded rail
- Vibration Projections at Bore Hole Site V-2
- Vibration Projections at Bore Hole Site V-3
- Vibration Projections at Bore Hole Site V-4
- Vibration Projections at Bore Hole Site V-5

Table A-1 Construction Equipment Maximum Noise Limits and Usage Factors

Construction Equipment	Maximum Noise Level at 50 feet (dBA, slow)	Usage Factor
Auger Drill Rig	85	20%
Backhoe	80	40%
Bar Bender	80	20%
Blasting	94	1%
Boring Jack Power Unit	80	50%
Chain Saw	85	20%
Clam Shovel	93	20%
Compactor (ground)	80	20%
Air Compressor	80	40%
Concrete Batch Plant	83	15%
Concrete Mixer Truck	85	40%
Concrete Pump	82	20%
Concrete Saw	90	20%
Crane	85	20%
Dozer	85	40%
Dump Truck	84	40%
Excavator	85	40%
Flat Bad Truck	84	40%
Front End Loader	80	40%
Generator (25 KVA or less)	70	50%
Generator (over 25 KVA)	82	50%
Gradall	85	40%
Grader	85	40%
Horizontal Boring Jack	80	25%
Hydraulic Break Ram	90	10%
Impact Pile Driver	95	20%
Insitu Soil Sampling Rig	84	20%
Jackhammer	85	20%
Mounted Hammer (ram)	90	20%
Paver	85	50%
Pickup Truck	55	40%
Pneumatic Tools	8585	50%
Pumps	77	50%
Rock Drill	85	20%
Scraper	85	40%
Slurry Plant	78	100%
Slurry Trenching Machine	82	50%
Soil Mix Drill Rig (Jet Grouting)	80	50%
Tractor	84	40%
Vacuum Excavator	85	40%
Vacuum Street Sweeper	80	10%
Vibratory Concrete Mixer	80	20%
Vibratory Pile Driver	95	20%
Welder	73	40%
All Other Equipment > 5 HP	85	50%

Source: CA/T Noise Specification 721.560

Figure A-1 Hourly Noise Results at Site N-2 (9/22/09 to 9/23/09)

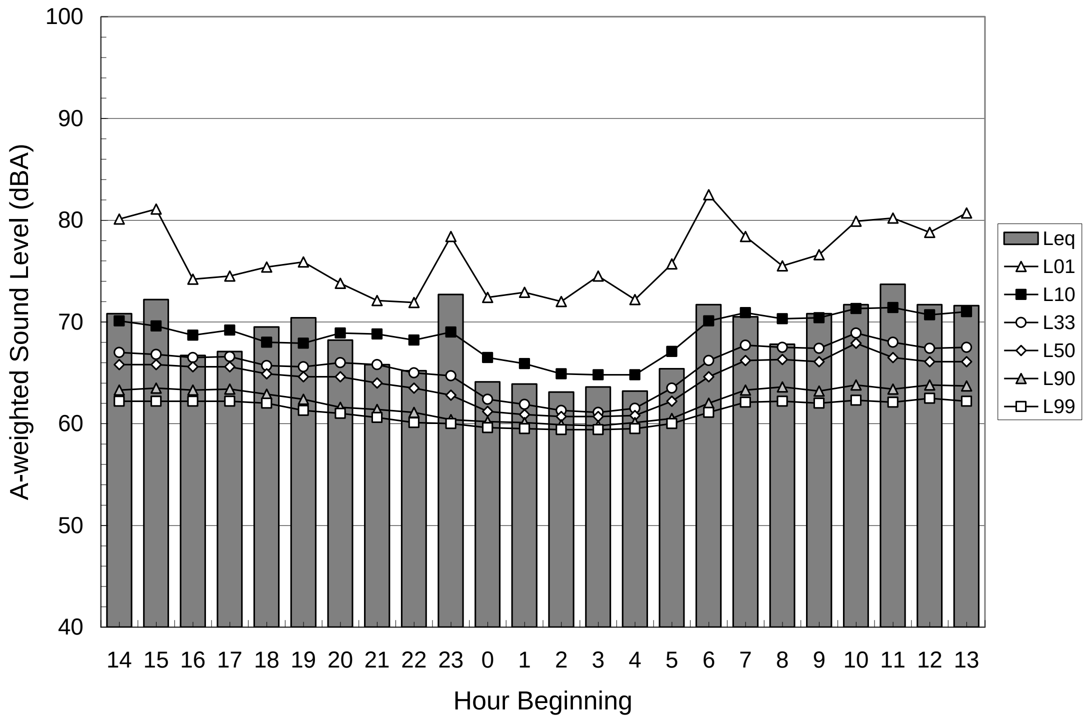

Figure A-2 Hourly Noise Results at Site N-2 (9/23/09 to 9/24/09)

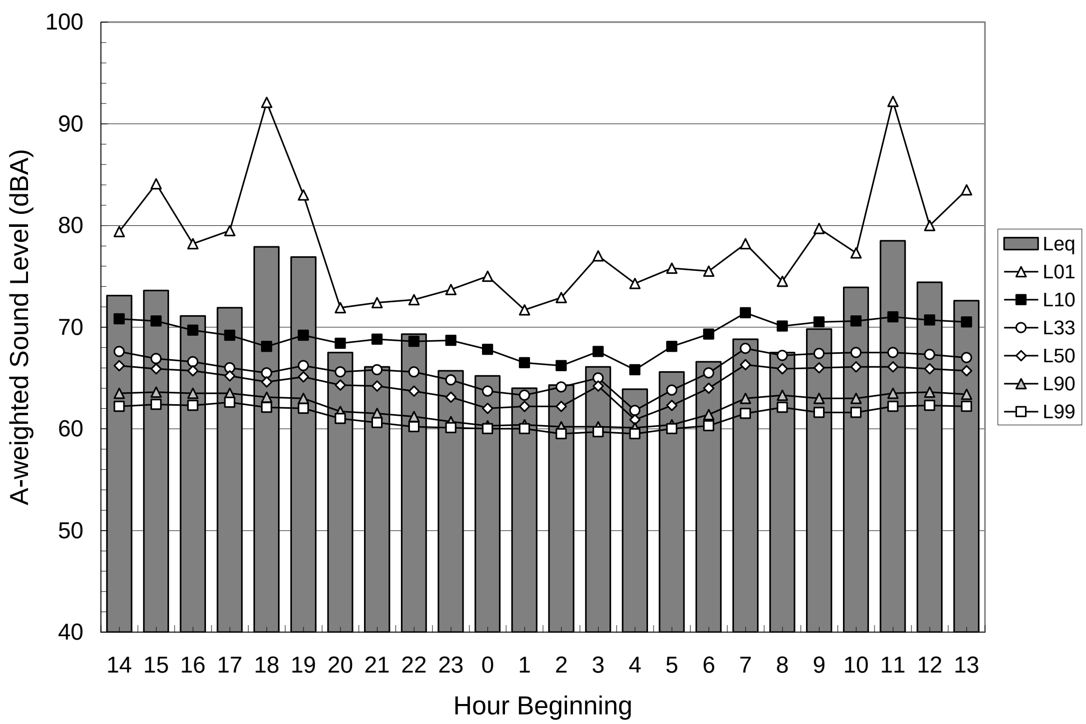

Figure A-3 Hourly Noise Results at Site N-5 (9/22/09 to 9/23/09)

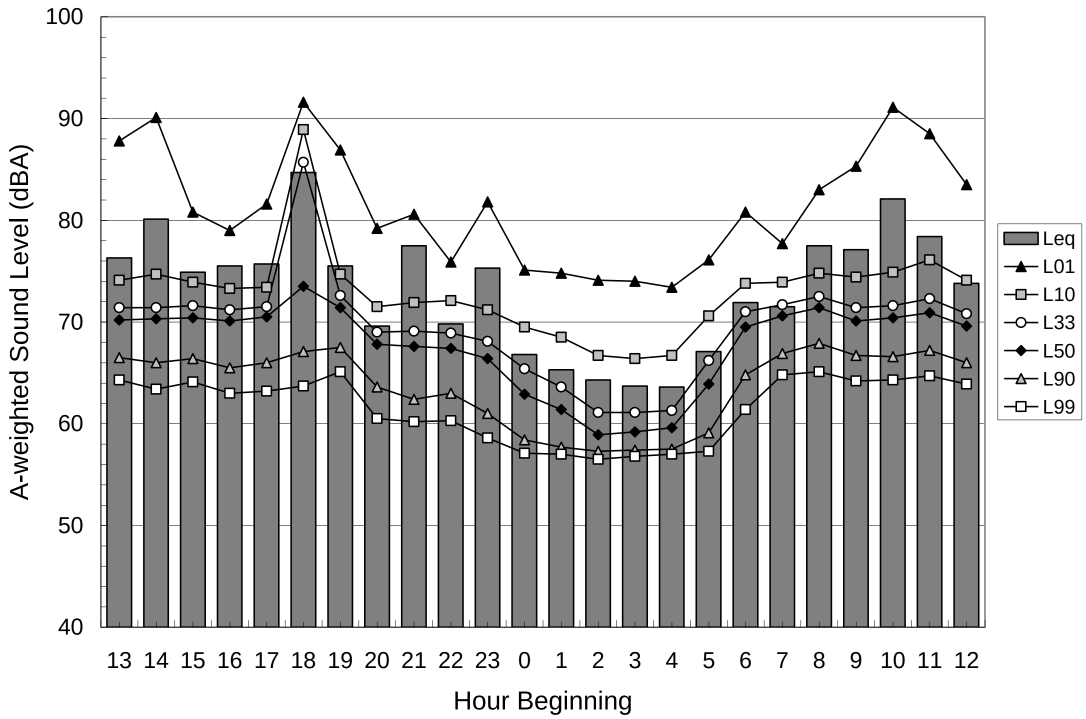

Figure A-4 Hourly Noise Results at Site N-5 (9/23/09 to 9/24/09)

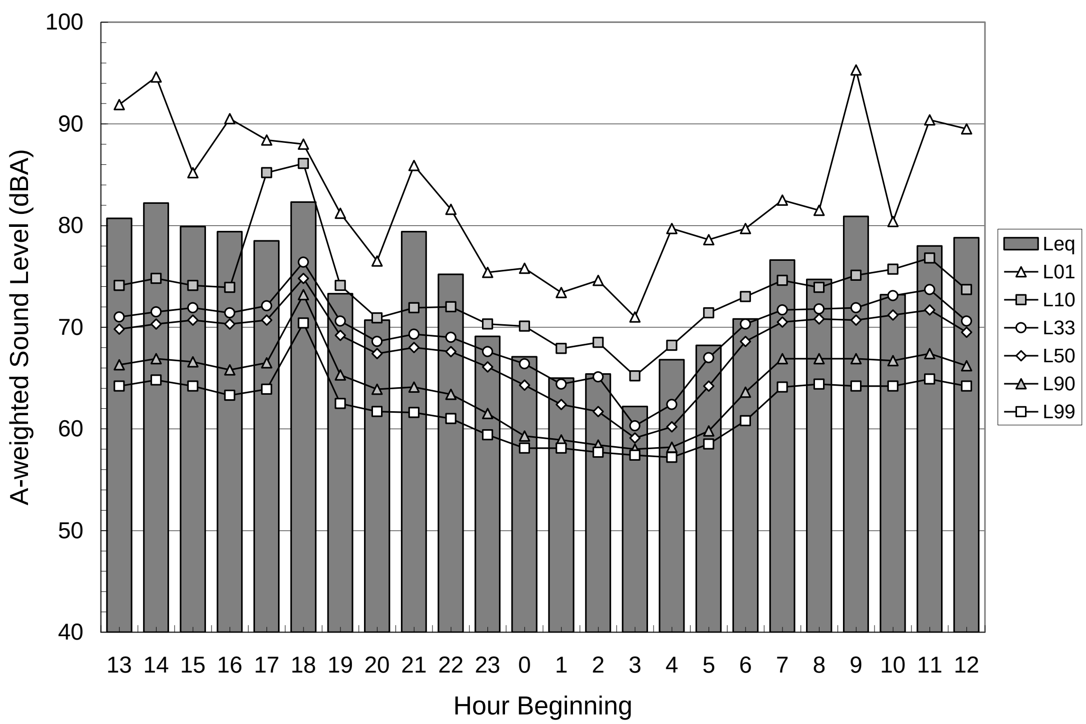

Figure A-5 Ambient Vibration Measurements at MGH

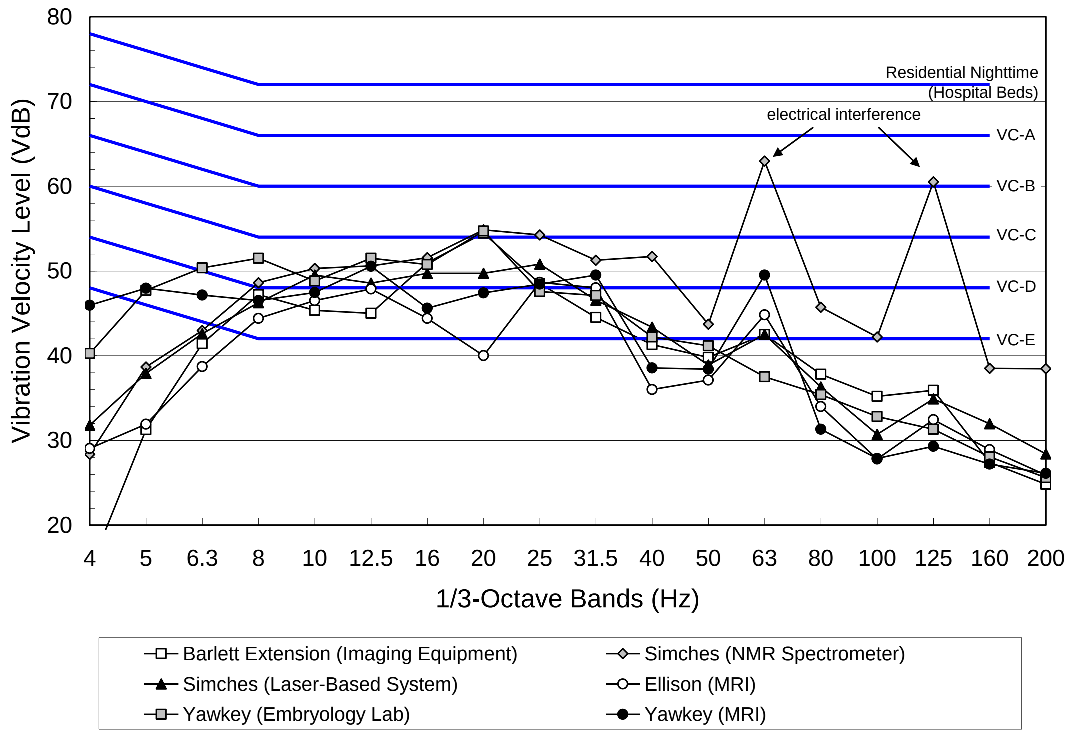

Figure A-6 Ambient Vibration Measurements at MEEI

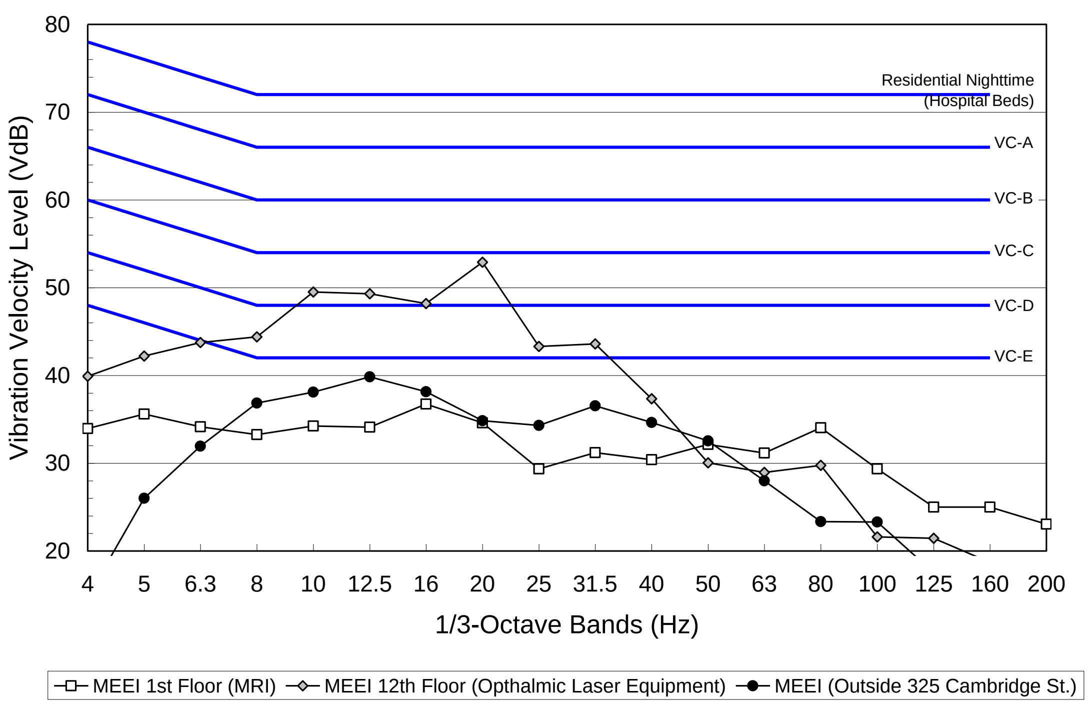

Figure A-7 Vibration Levels of Blue Line Trains Measured between Government Center and Bowdoin Stations

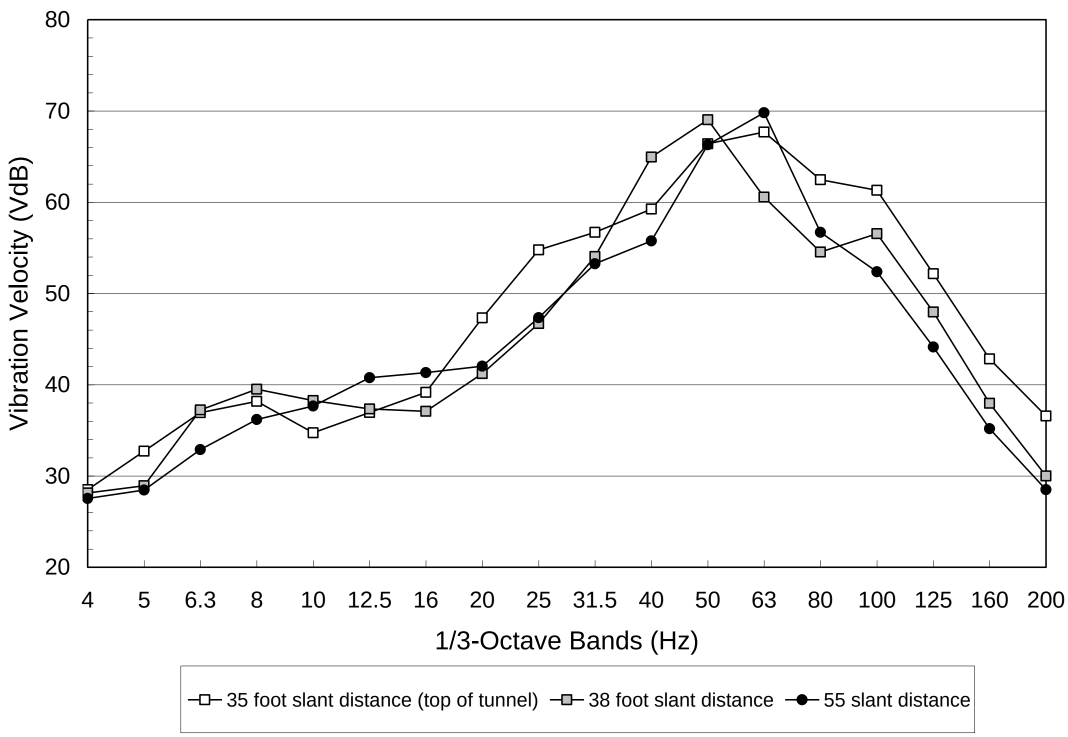

Figure A-8 Force Density of MBTA Blue Line Trains at 15 mph on Continuous-Welded Rail

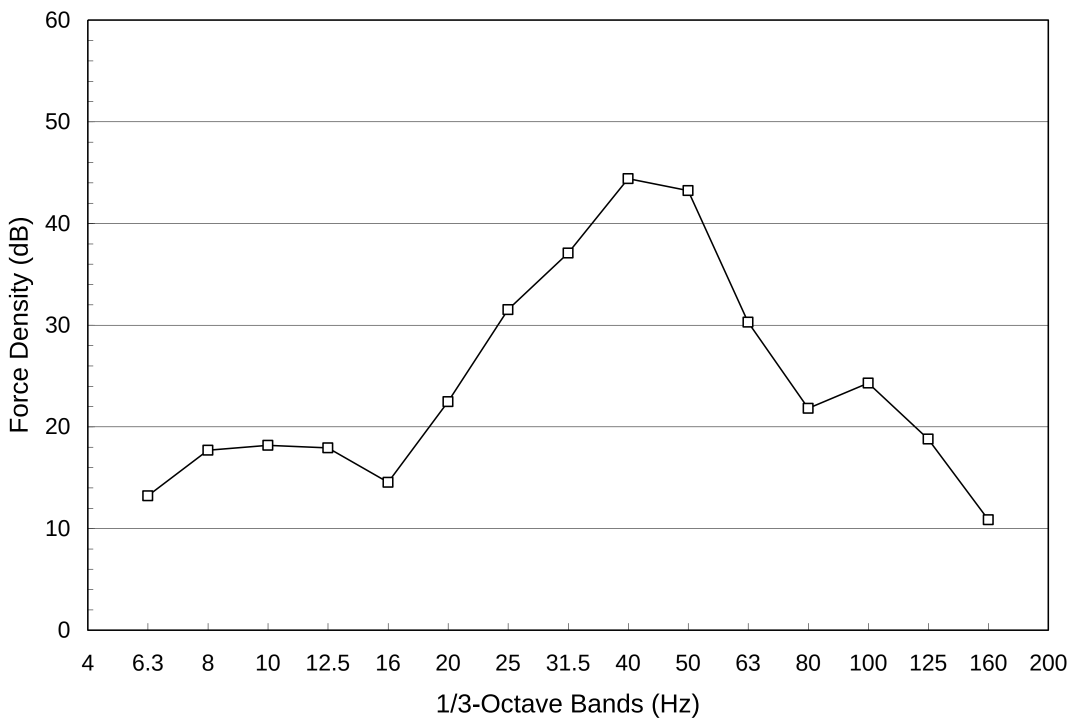

Figure A-9 Vibration Projections for Site V-2: Cambridge St and Lynde St

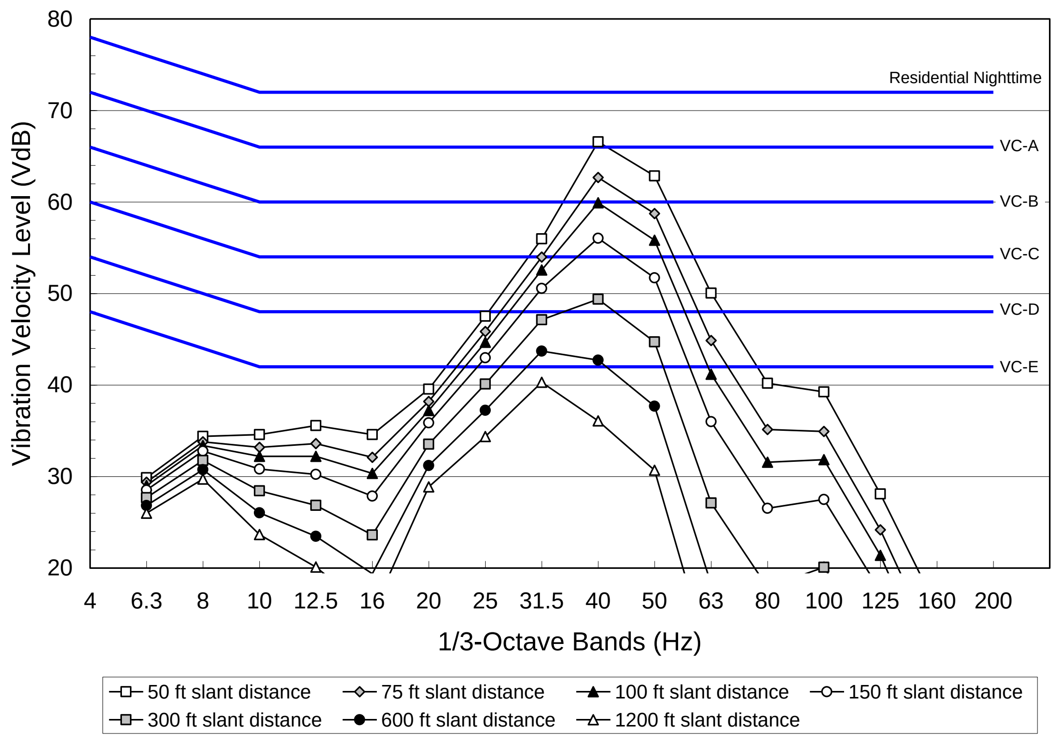

Figure A-10 Vibration Projections for Site V-3: Cambridge St and Hancock St

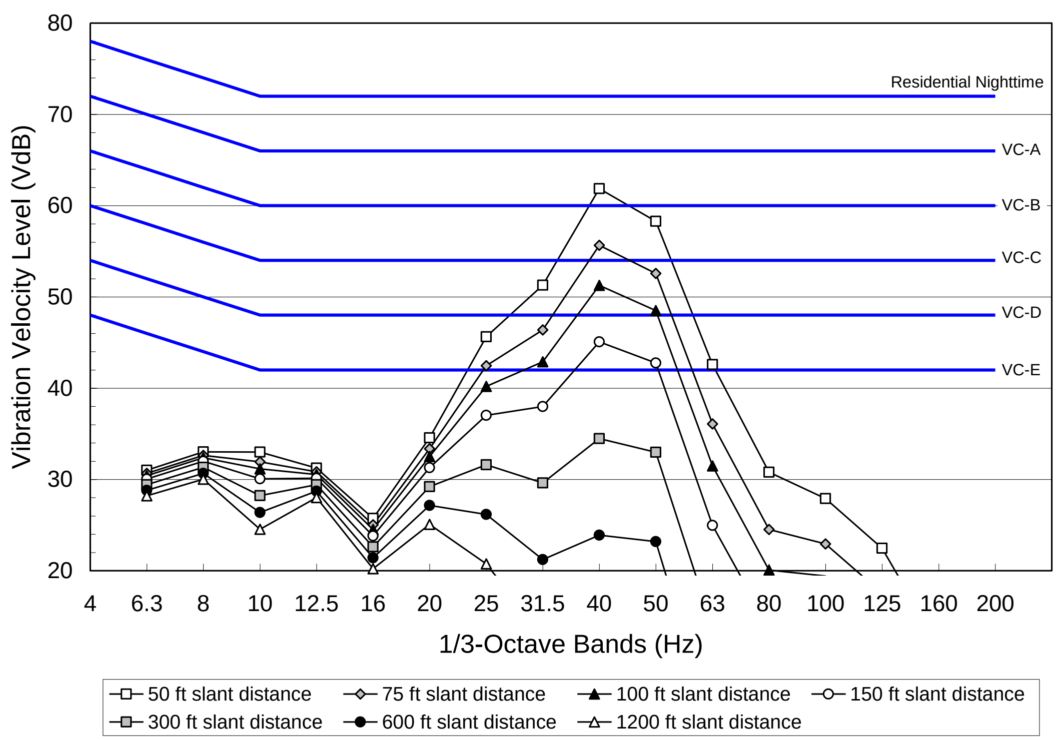

Figure A-11 Vibration Projections for Site V-4: Cambridge St and Blossom St

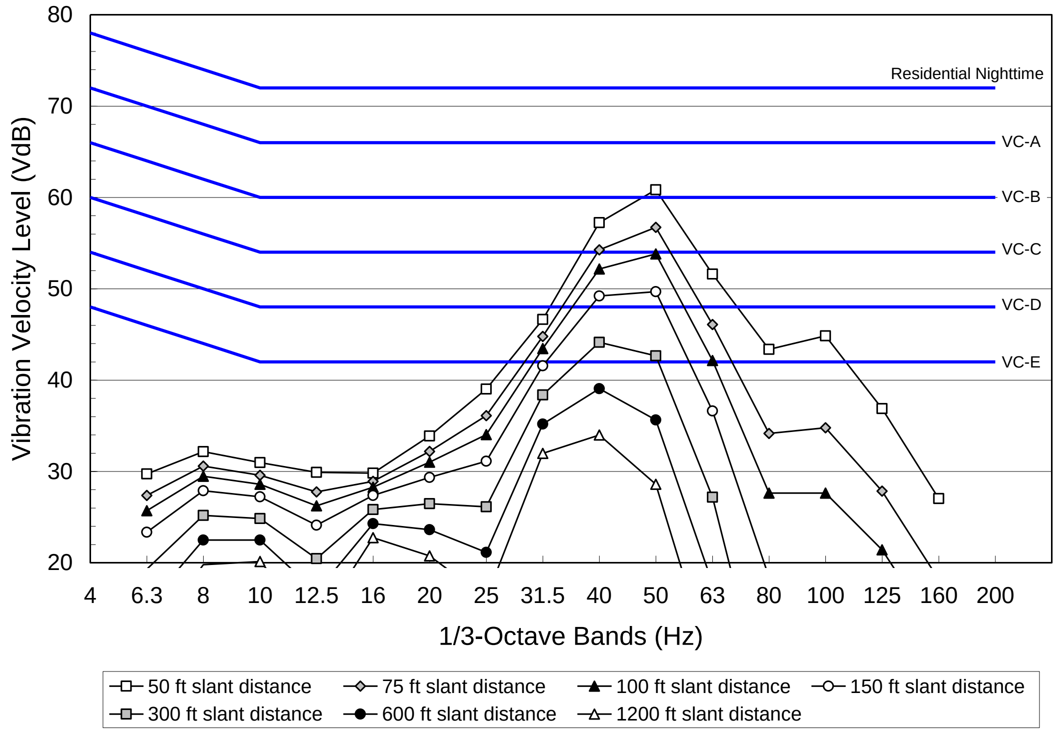

Figure A-12 Vibration Projections for Site V-5: Cambridge St and Grove St